QUALITY CONTROL IN PLYWOOD INDUSTRY—p. 221

Forest Products Journal

Vol. VII, No. 7 July, 1957

FPRS National Meeting and Suppliers Exhibit Attract Nearly 700 Registrants—p. 5-A

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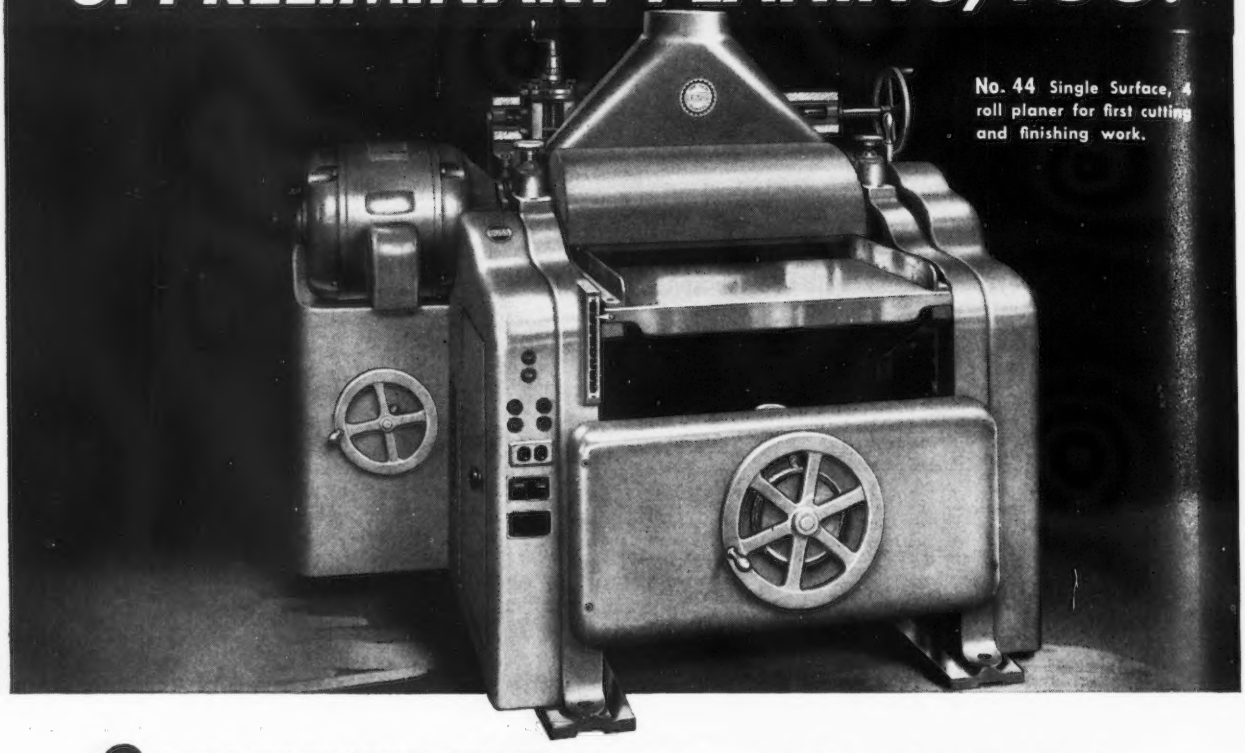

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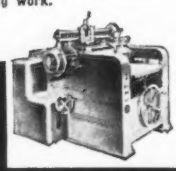

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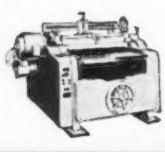

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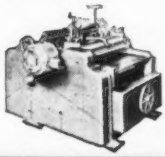

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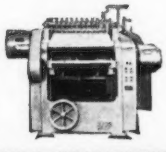

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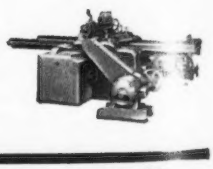

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THE FOREST PRODUCTS JOURNAL is published monthly by the Forest Products Research Society, P. O. Box 2010, University Station, Madison 5, Wisconsin. Entered as Second-Class Matter, April 1952 at the Post Office, at Madison, Wisconsin.

Annual subscription rate, $15.00; single copies $1.00, except October Yearbook Number, $4.00. Annual subscription rate is $11.25 with voting, associate, and supporting memberships in the Society. Remittances should be made payable to the Forest Products Research Society.

Correspondence on editorial matters should be addressed to the Editor, at the Executive Office. The Society is not responsible for views expressed in publications.

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IMPORTANT FPRS DATES

August: Upper Mississippi Valley Section Meeting, International Falls, Minn.

Sept. 27–28: Inland Empire Section Meeting, Omak, Wash.

Oct. 7–8: Pacific Northwest Section Meeting, Portland, Ore.

Oct. 21–22: Mid-South Section Meeting, Crossett, Ark.

Oct. 31–Nov. 1: Northeast Section Meeting, New York City

Oct. 31-Nov. 1: Carolinas–Chesapeake Section Meeting, Roanoke, Va.

June 22–26, 1958: Twelfth National Meeting, Madison, Wis.

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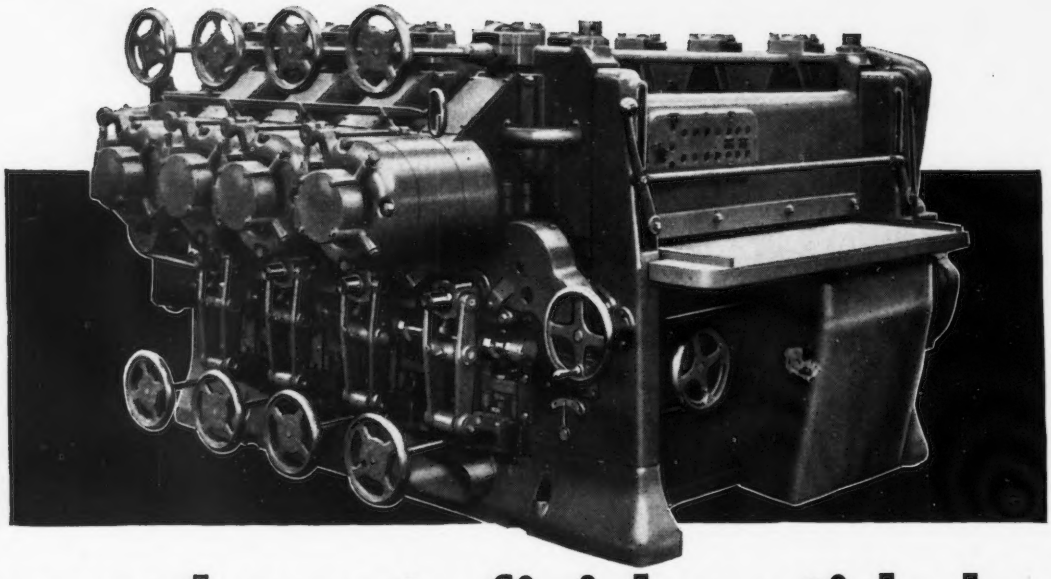

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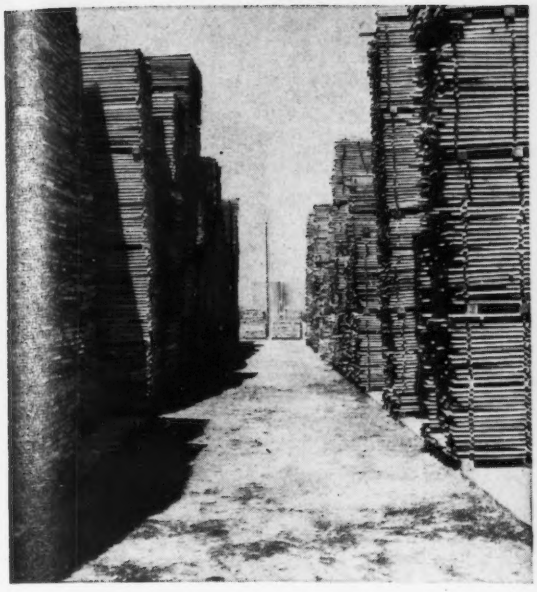
Both mills are finishing particle board with a Yates-American Double-Deck Sander and are removing up to 3/16″ of stock. This is what they report on sandpaper life:

First two pairs of drums	**1200 to 1500 hours**
Third pair of drums	**500 to 700 hours**
Fourth pair of drums	**150 to 200 hours**

We repeat — these are not *our* figures. They've been furnished to us by *two different mills* and have been confirmed and re-confirmed.



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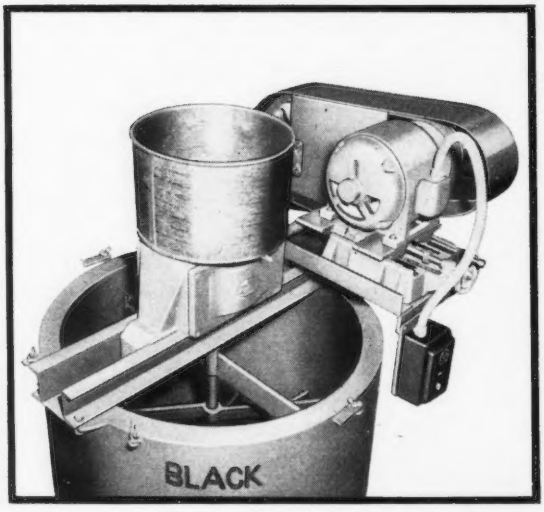

TWO-WAY AGITATION ▶

To the right is a partial view of a 60 gallon cold glue mixer arranged with a variable speed drive and water jacket. The covers have been removed showing accessibility for cleaning, and also the double agitator arrangement. Note the thick double walled tank permitting free circulation of water for cooling the glue batch.

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FPRS NEWS-DIGEST

Volume VII JULY, 1957 Number 7

National Meeting Speakers Foresee 100% Utilization

Thiesmeyer and Foy View More Research as Key to Realization of Industry's Goal

The future of the forest products industry belongs to those who prepare for it today. If you have any doubts about it, just ask any of the more than 684 (official) registrants at the recent FPRS 11th National Meeting, held at Buffalo, June 23–28.

Dr. Lincoln R. Thiesmeyer, President of the Pulp and Paper Research Institute of Canada, in his keynote address, "Everything, *Including* the Smell," foresees a future in which not only will we recover the *solid* residues (representing more than one-third of our resource) now going to waste in our forests, and the *liquid* slurries and solutions spent in our pulp mills (containing millions of tons of useful chemicals), but also to a lesser degree the *gaseous* effluents of these industries. That's 100 per cent utilization, a somewhat Utopian vision today, but one which can and will be met. To do so will require courageous decisions backed by heavy investment in research on the part of an ever more-enlightened wood industry management.

KEYNOTE SPEAKER Dr. L. R. Thiesmeyer addressing General Session.

FPRS PRESIDENT Ralph H. Bescher opened the General Session.

Some of the encouraging signs which Dr. Thiesmeyer points to are:

- The growing trend toward technically-trained men in contrast with financially-trained men taking over the reigns of management.
- The "conversion" in management thinking that is taking place, a change from the archaic ideal of growing "more cellulose per acre, *any* kind, just more," to growing "on each acre, as fast as possible, trees having the exact properties we want for the kind of products we want to manufacture."
- The growing awareness that the forest is an integral part of the whole manufacturing plant and should be treated as such. Improvement of the forest is not a long-range proposition but a current one; therefore any expense incurred or income derived should be figured into current operating costs.
- The need for a "revolution" in thinking when it comes to harvesting methods. Economic pressures from skyrocketing labor costs demand it. Present piecemeal mechanization of various logging and handling operations (at best they leave 30 per cent of the trees in the forest) are not the answer. Some daring concept of continuous vs. batch operation, such as chipping in the woods and conveying to the mill by means of pipeline, monorail or cableway to eliminate the vast array of men and machines now required, appears to be the solution, as proven in other and more advanced industries.

To prove that such thinking is not Utopian, Dr. Thiesmeyer described a current project of his Institute which promises to have far-reaching effects not only on forest products but other processing industries as well. The project concerns development of a process to treat the entire spent liquor stream in sulphite and semi-chemical pulp mills to recover, initially, the inorganic chemicals and heat. It is known as "AST", short for atomized suspension technique. CHEMICAL ENGINEERING, Dec. 1955, acclaimed it as "a new unit operation in the whole field of chemical engineering because of the great range of processes to which it may be applied." The development is beginning to pay off, not only in pulp mill recovery but also in treating a wide variety of effluent in other industries.

Backing Dr. Thiesmeyer's long-range prognostications, luncheon speaker Fred C. Foy, president of the

LUNCHEON SPEAKER Fred C. Foy, president of Koppers Co., Inc.

Koppers Company, added more fuel to the fire for greater research in our time. Outlining its growth, he pointed to the fact that "in 1926 we spent $2½ million for forest products research; in 1953 we invested $50 million," and "prospects for the future are for even greater intensification of research efforts." How important is research to our industry and we as individuals? "Let's not kid ourselves," he said, "research is everybody's business, for in these days progress is synonymous with survival; and research is the vital ingredient of progress."

Underlying progress in wood research has been a little-noticed, "subtle" change in our idea about wood. Gradually we have come to look at it as a *quality* material in contrast with viewing it as an abundant, cheap construction material. Contributing to this quality concept have been numerous technical developments such as lamination, treating and others. Upgrading in quality has also brought an increase in the per capita consumption of quality materials as plywood, paper and particle boards. It has also brought an increase in the price of wood, while at the same time making it measurably more competitive with other structural materials.

On future research Foy added, "I firmly believe there are areas of research that should be the sole responsibility of industry. There are other areas, however, in which the fruit of more-or-less "pure" forestry research may be the food to encourage economic growth and welfare of a sizeable segment of our nation, and there is no reason why government and state agencies could not carry on more work in this direction in much the same fashion that they now carry on other agricultural research to aid the farmers of the nation.

Underlying Problems

Mr. Foy outlined six basic problems, the solution of which would contribute most to the progress of forestry and forest products.

1. Means should be found to expand and intensify the utilization of hardwoods by the pulp and paper industry.

2. We should obtain the technical and engineering information on which to base a diversified chemical industry utilizing low grade wood as a raw material.

3. Develop means of using lower grade solid wood by finding applications in which these woods could be economically utilized by combining them with other materials, such as impregnated paper overlays.

4. Develop economical and satisfactory methods to make wood more dimensionally stable.

5. Continue to develop less expensive and better methods of wood preservation and for the fireproofing of wood.

6. Develop management methods dependent on genetics and selection to improve the quality and yields of our timberlands.

The foregoing kind of thought-provocation was typical of the four-day meeting during which 49 papers, 4 panel discussions, 13 Division meetings and numerous other committee meetings were held.

Other highlights of the meeting, third largest in the Society's history, included the Suppliers Exhibit of materials, equipment and supplies displayed by 57 companies and institutions; the traditional Paul Bunyan outing at Niagara Falls attended by an estimated 600 persons and sponsored by 52 companies; and the four major and 13 "open house" plant tours in the Buffalo area.

The official description of the 11th National Meeting and Suppliers Exhibit will appear in the October "Yearbook" issue of the JOURNAL; as will the full texts of Dr. Thiesmeyer's and Mr. Foy's addresses. Papers and floor discussion will appear in ensuing issues of the JOURNAL.

Frank H. Kaufert Installed as Eleventh President of FPRS

F. H. KAUFERT

Dr. Frank H. Kaufert was installed as FPRS President during the Official Luncheon at the Eleventh National Meeting in Buffalo. He succeeds Ralph H. Bescher, Pittsburgh, Pa., who will remain on the Executive Board as Past President.

President-Elect for the coming year is W. Jeter Eason, Vice-President, Nickey Brothers, Inc., Memphis, Tenn. Elected to the Vice-Presidency was Dr. E. S. Harrar, Dean, Graduate School of Forestry, Duke University, Durham, N. C.

W. J. EASON

E. S. HARRAR

Donald K. Saunders, Northeast Region, and T. S. Veazey, Jr., Northwest Region, were elected to three-year terms on the Executive Board. The former is President, Saunders Brothers, Westbrook, Maine, and Veazey is Assistant Research Engineer, Anaconda Copper Mining Co., Butte, Mont.

Elected to the National Nominating Committee for 1957–58 were: R. C. Rietz, U. S. Forest Products Lab, Madison, Wis.; A. L. Mottet, Long-Bell Division, International Paper Co., Longview, Wash.; R. W. Wellwood, University of British Columbia, Vancouver, B. C.; and N. V. Polatika, Timber Engineering Co., Washington, D. C. Past presidents named to serve on this committee are Lester J. Carr and Moss B. Christian.

Three Executive Board Members Complete Terms

Three men completed terms on the FPRS Executive Board during the recent National Meeting in Buffalo.

M. B. CHRISTIAN

Moss B. Christian retired from the Board after seven years' service. Director of Research for Chicago Mill and Lumber Co., Tallulah, La., he was South-Central Regional Board Member, 1949–52; Vice-President, 1952–53; General Chairman of the Seventh National Meeting, 1953; President-Elect, 1954–55; President, 1955–56; and Past President, 1956–57.

J. D. RITCHIE

C. R. LOCKARD

John D. Ritchie, Special Products Director, Douglas Fir Plywood Association, Tacoma, Wash., completed a three-year term as Northwest Regional Board Member. He served as General Chairman of the Society's 1955 National Meeting in Seattle, Wash.

Charles R. Lockard served as Northeast Regional Board Member during the past year and was General Chairman of the 1957 National Meeting. He is Chief, Forest Utilization Service, Northeastern Forest Experiment Station, Upper Darby, Pa., and is a past chairman of the FPRS Northeast Section.

More than 700 Participated in National Meeting Activities

GENERAL CHAIRMAN Charles R. Lockard was toastmaster for the Official Banquet. Meeting committee members and wives were seated at head table.

SECTION OFFICERS advisory committee met with National Executive Board.

DIVISION CHAIRMEN LUNCHEON

INDUSTRY–EDUCATION DIVISION meeting was one of many shirt-sleeve sessions throughout the week.

PAST PRESIDENTS' DINNER was attended by, left to right, M. B. Christian, R. M. Carter, Mrs. Christian, J. F. Hamilton, Mrs. R. D. Pauley, R. H. Bescher, E. G. Locke, R. D. Pauley, Mrs. Bescher, K. G. Chesley.

WOOD AWARD winner R. L. Youngs is congratulated by J. F. Kaellisch, Wood & Wood Products magazine. Looking on are A. J. Panshin, second place winner C. W. McMillin, and H. C. Moser, chairman of judges.

LAMINATED WOOD FIBER panels coming off 207-foot laminating machine are viewed by registrants touring plant of Upson Co., Lockport, N. Y.

PLYWOOD PRESSING operation attracted registrants' interest during tour of Kittinger Co., Buffalo.

AWARD OF MERIT citations were presented by V. C. Hogren, Hitchcock Publishing Co., to E. F. Anderson, Monsanto Chemical Co.; W. Henrich, Architectural Woodwork Institute; E. S. Johnson, N. C. State College; C. A. Luce, West Coast Lumbermens Assoc.; A. E. Oviatt, Timber Structures, Inc.; and (not shown) R. W. Pettersen, St. Paul and Tacoma Lumber Co.

Capacity Crowd Attended Official Luncheon at FPRS 11th National Meeting

Typical Booths at FPRS Suppliers Exhibit in Buffalo

Exhibit Chairman R. C. Deckert and committee member H. L. Bennett.

Masonite Corp.

Perkins Glue Co.

National Casein Co.

Fjellman American, Inc.

Standard Dry Kiln Co.

Moore Dry Kiln Co.

Kennametal, Inc.

Reichhold Chemicals, Inc.

National Adhesives

Mater Engineering

Yates American Machine Co.

Peter Cooper Corps.

Columbia Engineering Co.

Ekstrom, Carlson & Co.

NEW OFFICERS of Northern California Section are shown with President R. H. Bescher and Regional Board Member R. H. Berry. Left to right are: Secretary–Treasurer Peter Field, Past Chairman H. N. Stephenson, Chairman N. T. Shelton, Vice-Chairman R. M. Kuhn, Trustee B. C. Manson, Mr. Bescher, Mr. Berry, and Trustee Fred E. Dickinson.

Shelton Elected Chairman of Northern California Section

N. Thomas Shelton, Diamond Match Co., was elected Chairman of the Northern California Section at the Annual Spring Meeting May 2–3, in Berkeley, Calif. Other new officers are: Vice-Chairman, Robert M. Kuhn, Rees Blow Pipe Manufacturing Co.; Secretary–Treasurer, Peter Field, Ivory Pine Co. Elected trustees were Byrne C. Manson, Simpson Redwood Co., two years; and Fred E. Dickinson, California Forest Products Laboratory, one year.

Production, economics and marketing of particle board was the theme of the meeting, Nine papers were presented, with 146 persons attending the technical sessions.

Dinner speaker Paul R. Bonderson, California State Water Pollution Board, discussed "Use of Streams and Tidewater for Effluent Disposal from Wood Utilization Plants". FPRS President Ralph H. Bescher reported on the national organization at the banquet. Past president Lester J. Carr introduced Mr. Bescher.

A tour of the Forest Products Laboratory at the University of California concluded the meeting. Fred E. Dickinson, Director, outlined facilities and objectives.

Four Plants Visited During Pacific Northwest Meeting

A trip to three scragg-type stud mills opened the Pacific Northwest Section Spring Meeting May 13–14. Mills visited were owned by Paul B. Hult Lumber Co., Round Prairie Lumber Co., and Sun Studs, Inc. Headquarters for the two-day meeting was the Umpqua Hotel, Roseburg, Ore.

George E. French, United States Plywood Corp., spoke on better utilization of wood residues, particularly in the plywood industry, at the banquet on May 13. According to Mr. French, sawmill operators convert into finished products only 35 per cent and plywood firms just 43 per cent of fiber brought into the mill. Mr. French suggested that greater use of residues could be achieved with better quality control, more mechanization, and development of special products.

Steve Batori, Controls and Communications Co., moderated a panel discussion on stud manufacture. Other participants were Paul B. Hult, Paul B. Hult Timber Co.; George Goodman, Douglas Studs, Inc.; Clifford Baxter, Wilber Lumber Co.; Fred Sohn, Sun Studs Inc.; Ralph Sanstede, Round Prairie Lumber Co.; and Sig Wolfe, Keystone Machinery Co.

"Essentials for a Profitable Western Hardwood Operation" was the title of a paper presented by Jack R. Pfeiffer, Oregon Forest Products Laboratory, at the May 14 technical session. Wayne E. Maynes, Touceh, Niven, Bailey and Smart, presented a paper on "A New and Revolutionary Method of Cost Finding for Plywood Companies". The final paper of the session was "Beveled Siding from Common Lumber" by R. G. Frashour and W. H. Cooke, formerly of the Oregon Forest Products Laboratory, Corvallis, Ore.

The meeting closed with a trip to the Roseburg Lumber Co.

Pacific Northwest Section Plans Meeting in October

"Edge-and End-Gluing of Forest Products" will be the general theme of the Pacific Northwest Section Meeting October 7 and 8, according to P. L. Northcott, Section Secretary. The meeting at the Multnomah Hotel, Portland, Ore. will include technical sessions and field trips related to the general theme.

Local arrangements co-chairmen are Robert Conklin, Cascades Plywood Corp., and Elmer Matson, Pacific Northwest Forest Experiment Station, both of Portland.

Yale and Michigan Graduates Win Wood Awards Competition

Robert L. Youngs, Madison, Wis., and Charles W. McMillin, Ann Arbor, Mich., were winners of the 8th annual Wood Awards competition, sponsored by WOOD & WOOD PRODUCTS magazine in cooperation with FPRS. The awards, given for outstanding graduate student research in forestry and wood technology, were presented by J. F. Koellisch, editor and manager of WOOD & WOOD PRODUCTS, at the opening general session of the National Meeting in Buffalo.

Youngs won $350 and a certificate for his paper on "Mechanical Properties of Red Oak as Related to Drying," based on a dissertation which he recently submitted as a candidate for a Ph.D. in Forestry at Yale University. He has been employed at the U. S. Forest Products Laboratory since 1951, conducting research on wood drying stresses, temperature and moisture content effects, and plastic laminates. He holds a B. S. degree from New York State College of Forestry and M.W.T. degree from University of Michigan.

"The Relation of Mechanical Properties of Wood and Nosebar Pressure in the Production of Veneer," was the title of McMillin's paper. He received $150 and a certificate. Holder of a B. S. degree from Purdue University, he received a Master of Wood Technology degree from the University of Michigan in June.

A total of 15 entries, representing seven colleges and universities, were judged by a staff selected by Dr. A. J. Panshin, chairman of the FPRS Industry-Education Division. Judges were: H. C. Moser, vice-president, Gamble Bros., Inc.; Fred E. Dickinson, director, California Forest Products Laboratory; and R. R. Blumenstein, assistant director of research, Timber Engineering Co.

On The Cover

Registration desk (upper left) at 11th National Meeting June 23–25 in Buffalo was busy spot as nearly 700 FPRS members and guests registered for meeting. At upper right, Frank H. Kaufert accepts gavel of presidency from Ralph H. Bescher during Official Luncheon. Looking on are President-Elect W. J. Eason and principal speaker Fred C. Foy, Koppers Co. president. Nearly 60 companies and institutions participated in Supplies Exhibit (lower left), which was open throughout the week. Smorgasbord supper (lower right) at Brock Monument Park, Ontario, and tour of Niagara Falls was entertainment highlight of meeting. More than 50 firms sponsored this traditional Paul Bunyan event.

Particle Board Theme of Northern California Section Meeting

NORTHERN CALIFORNIA SECTION MEETING speakers included, left to right above, President R. H. Bescher, L. N. Erickson, G. G. Marra, D. R. Seip, and C. C. Heritage; below, H. Sandstrom, D. L. Hunt, H. D. Turner, J. E. Marian, and P. R. Bonderson.

Laboratory Tour Featured at Midwest Section Meeting in Peoria

MIDWEST SECTION meeting May 9–10 at Peoria, Ill., was attended by some 35 members, shown here at the U. S. D. A. Northern Utilization Research Laboratory.

SCALE MODEL papermaking machine costing $25,000 is used to make experimental runs of paper from straw, bamboo, bagasse, and agricultural residues.

George Holiman, manager of Hirc[illegible] Walker & Sons cooperage divi[illegible]n, discussed: "Procurement Prob[illegible]ms for White Oak."

R. D. Behm, executive secretary, Hardwood Plywood Institute, spoke on: "Quality and Specifications of Prefinished Wall Materials." At left is Section Secretary Bob Archambeault.

David E. Herrick, U. S. Forest Service, and R. M. Reed, Caterpillar Tractor Co., discuss harvesting of pulpwood.

Building Fund Drive Nears $19,000

Large and small contributions reported from FPRS's 6 Regions and 14 Sections throughout U. S. and Canada.

The fund-raising campaign for the Society's new headquarters building in Madison, Wisconsin, was formally launched by Chairman Raymond H. Berry, Scott Lumber Co., Burney, Calif., as of April 15, 1957. Although members of the Society in all regions have cooperated excellently and worked very hard, the totals still remain considerably below those required to achieve our goal of $60,000. Mr. Berry believes that an organization of the size and international scope of FPRS should have little difficulty in attaining this objective and under ordinary circumstances the industry should reach or over-subscribe the goal. By action of the National Executive Board at the National Meeting in Buffalo, the Fund-Raising Drive deadline date has been extended to October 1.

Berry emphasizes that no amount is too great or too small to help us attain our objective of a home office building to be under construction by the time of our 12th National Meeting in Madison next June 22–27. (We hope you will use the convenient coupon below to make your personal contribution. All donations are tax-deductible.)

Cash contributions or pledges in major amounts have been received in recent weeks from the following organizations and individuals:

Cash Contributions:

Arcata Redwood Co., Arcata, Calif., $150
George S. Armstrong & Co., Inc., New York, N. Y., $50
Bennett Veneer Factors, Inc., Portland, Ore., $100
Bradley Lumber Co. of Arkansas, $100
Byles–Jamison Lumber Co., $100
Canadian Forest Products Ltd., New Westminster, B. C., $200
Cascades Plywood Corp., Lebanon, Ore., $200
Collins Pine Co., Portland, Ore., $500
Connor Lumber & Land Co., Laona, Wis., $100
Richard M. Connor, Laona, Wis., $50
L. N. Dantzler Lbr. Co., Perkinston, Miss., $50
Decar Plastic Corp., Middleton, Wis., $100
FPRS Pacific Southwest Section, $100
Jamestown Veneer & Plywood, Jamestown, N. Y., $100
Karlen–Davis Co., $100
Kaul Trustees, Birmingham, Ala., $100
Lightsey Brothers, Miley, S. C., $50
The Lilly Co., High Point, N. C., $50
Roy O. Martin Lumber Co., Alexandria, La., $100
Medford Corp., Medford, Ore., $50
Moore Dry Kiln Co., Jacksonville, Fla., $50
Murco Foundation, Wausau, Wis., $100
Nicholson Mfg. Co., Auburn, Wash., $200
Ozan Lbr. Co., Prescott, Ark., $100
Perkins Glue Co., Lansdale, Pa., $250
Quaker Oats Co., $100
B. M. Root Co., York, Pa., $100
Singer Mfg. Co. (Quebec), Thurso, Quebec, $100
Southern Plaswood Corp., Hope, Ark., $100
Southern Wood Treaters, Inc., $50
Standard Dry Kiln Co., Indianapolis, Ind., $50
E. J. Stanton & Son, Inc., Los Angeles, Calif., $50
Sullivan Hardwood Lumber Co., San Diego, Calif., $50
Sun Studs, Inc., Roseburg, Ore., $50
Tennessee Wood Products & Chemical Corp., Nashville, Tenn., $200
Thomasville Chair Co., Thomasville, N. C., $100
Timber Structures, Inc., Portland, Ore., $100
Townsend Lumber Co., Inc., Stuttgart, Ark., $50
Urbana Lumber Co., $50
Lewis C. Wallace, Brookfield Center, Conn., $50

Pledges:

American–Marietta Co., Seattle, Wash., $500
Broyhill Furniture Factories, Lenoir, N. C., $500
L. J. Carr & Co., Sacramento, Calif., $500
Hardwood Corp. of America; Williams–Brownell, Inc.; & Bemis Hardwood Lumber Co., Asheville, N. C., $400
Hollow Tree Lumber Co., Ukiah, Calif., $300
Turney Wood Products, Inc., Harrison, Ark., $50
U. S. Steel Homes, Inc., New Albany, Ind., $500
Urania Lumber Co., Urania, La., $10

Harrar Edits New Series of Encyclopaedia of Woods

Volume I of a series of a new version of *Hough's Encyclopaedia of American Woods* has been published by Robert Speller & Sons. The series will be distributed on a world-wide scale by Interscience Publishers, Inc., New York, and appear semi-annually.

Dr. E. S. Harrar, Dean of the Graduate School of Forestry, Duke University, and Vice-President of FPRS, is acting editor-in-chief of the entire undertaking. Each volume of the new version consists of two parts, the first a text written by Dr. Harrar containing up-to-date information on the habitat of the tree and the structure and utilization of woods.

The second part consists of three actual wood sections of each of 25 woods, many of them by the late Romeyn Beck Hough. Others will be cut as required using machines of his design.

Fifteen volumes dealing with 25 woods each will be devoted to American woods. Additional volumes will be devoted to European woods, exotic woods, and wood technology. Volumes I and II sell for $25 each.

NAFM Convention and Fair to be Held August 25–28

Up-to-date information in 11 different fields will be featured at the 29th annual convention of the National Association of Furniture Manufacturers August 25–28 at the Conrad Hilton Hotel, Chicago, according to John M. Snow, NAFM executive vice-president.

Held simultaneously with the convention will be the third annual NAFM Supply, Equipment and Fabric Fair with a total of 127 exhibitors assigned space to date. This year's Fair, it is reported, will be the largest display of its kind ever held for the furniture and woodworking industries. In 1956, more than 2,000 furniture and woodworking executives from 36 states and seven foreign countries attended the annual convention and trade fair.

"New Trends in Woods and Finishes" will be the subject of a convention talk by Burdett Green, executive

CONTRIBUTION OR PLEDGE CARD

Name _____

Address _____

I hereby (contribute) (pledge) my support to the proposed FPRS Executive Office Building to be erected as early as possible, consistent with conservative business practice, in Madison, Wisconsin.

(Check here for Contribution and enclose check or money order) ☐ $_____

(Check here for Pledge. We will invoice you for the amount of pledge during calendar year 1957) ☐ $_____

Signed _____

director of the Fine Hardwoods Association. Vincent E. Noltemeyer, author of the cost manual "Accounting and Cost Controls in the Hardwood Conversion Industry", will speak on "How to Cut Costs with Dimension".

Predicts Doubled Production of Particle Board by 1960

Continued expansion in the wood particle board industry is expected to more than double current production by 1960, according to James Dillon, vice-president, National Starch Products, New York. He released figures on the industry at the opening of National's Granite Board exhibit at the Design Engineering Show at the New York Coliseum.

The U. S. Department of Commerce reported 1956 production at 285 million sq. ft. of ¾-inch board, Dillon stated. Since then, 18 new facilities have gone into operation, bringing the total number of domestic plants to 47. Total annual combined capacity is now near 450 million sq. ft., he reported. If expansion continues at the present rate, the industry should be producing upwards of 900 million sq. ft. by 1960.

Expected expansion of the industry and growing demand for Granite Board, produced by the Structural Products Division of National Starch, has prompted the company to expand its production capacity more than 50 per cent. Mr. Dillon announced the expansion of production facilities at the recent FPRS National Meeting in Buffalo.

The firm believes that the greatest market potential for particle board exists in the residential building industry which consumes 70 per cent of all the lumber manufactured in the U. S. It is predicted that success in applying and marketing particle board products is more likely to be achieved by companies that consider it an engineering material rather than a lumber substitute.

Michigan Firm Announces Opening of Modern Automated Sawmill

Production of northern hardwood lumber has started at the newly completed sawmill of Calumet & Hecla, Inc., Calumet, Mich. Designed to produce 10 million board feet of lumber annually, the highly automated mill is turning out birch and maple lumber for furniture and flooring, as well as softwood industrial crating lumber and timbers for the firm's copper mines.

Key to efficient operation of the mill, according to President E. R. Lovell, is a hydraulically powered carriage that easily moves logs weighing a ton and more into precise position for cutting the highest percentage of quality boards. Sawed lumber is similarly moved through the mechanized mill via powered rollers and conveyors for trimming and edging operations.

All trimmings and slabs are automatically carried to a chipping machine, believed to be the first of its type in the Midwest, for conversion into raw material for wood-chemical industries. A railroad car load a day of sawdust is collected and sent to the firm's mine and smelter power plants for use as fuel.

Californian Elected President of Fir Plywood Association

New plywood construction techniques and promotion to help absorb production from the industry's 113 mills in Washington, Oregon, Montana, and California was the theme of the 21st annual meeting of the Douglas Fir Plywood Association. The meeting, held June 10–11 at Gearhart, Ore., was attended by more than 250 Western fir plywood manufacturers.

A. W. Agnew, vice-president of the Pacific Coast Co., Sonoma, Calif., was elected DFPA president. Eleven plywood mills were voted membership in the association.

Missouri Forestry Department Changed to School of Forestry

A full School of Forestry, operating within the Division of Agricultural Sciences, was recently created at the University of Missouri, Columbia. The school was established because of the rapidly increasing importance of forestry in Missouri's economic development and the subsequent demand for graduates in the research and supervisory field.

Dr. Ruthford H. Westveld, chairman of the department of forestry since its foundation in 1947, was named director of the new school.

ANNOUNCEMENT

To 1958 National Meeting Potential Authors

Technical sessions will be held on the following subjects at the 12th National Meeting in Madison, Wisconsin, June 22–27, 1958:

Industry Education
Wood Preservation
Drying
Logging
Lumber Manufacturing
Quality Control
Glues and Gluing
Veneer and Plywood
Chemical Utilization
Finishing
Machinery and Machining
Composition Board

If you wish to submit a paper for this meeting, your suggested title and brief description of the ultimate paper should be directed to either the FPRS Executive Office; Technical Program Chairman, W. Jeter Eason, Nickey Bros., 2700 Summer Avenue, Memphis 3, Tenn.; or to the individual Division Chairmen.

Your description should state the intended scope of the paper and individual features of the work that will in your opinion justify its inclusion on the National Meeting Program.

Carriage of new Calumet & Hecla sawmill easily brings log into position for cutting and moves it through the bandsaw at the flip of a lever.

Management Counseling Service Offered Wood Industries

G. W. STANLEY, JR.

Formation of a new management counseling service, George Stanley Associates, has been announced by George W. Stanley, Jr., Tomahawk, Wis. Designed to serve the wood and wood products industries, the firm is staffed by men with experience in all phases of wood from tree to marketing of finished products. It is believed to be the first time that both management and technical services will be available from one source for these industries.

Services being offered include: business and plant management, economic surveys, market studies, overall plant review, preparation of budgets, forecasts, profit and loss statements, cost controls, plant layout, equipment studies, traffic and rate reviews, and quality control systems.

George W. Stanley, Jr. is past Midwest Section Chairman, FPRS, and a member of several engineering and management associations. A graduate of Brown University, he has had several years of experience as general manager of plants employing from 100 to 1200 employees.

Michigan State Receives Grant for Millwork Training Course

A grant of $5,500 has been made to Michigan State University by the Northern Sash & Door Jobbers Association for the development of a millwork correspondence course for industry personnel. The 20-week course will be written by W. B. Lloyd, professor of forest products, MSU, in cooperation with NSDJA.

Prof. Lloyd will visit and work with millwork plants, jobber warehouses, and retail lumber yards to compile up-to-date data on millwork production, distribution, and sales. The course will include: basic house construction concepts, blueprint reading, millwork product detailing and application, and proven sales techniques.

Washington Institute Plans Study of Sawdust and Bark Uses

Active investigation is planned by the Washington Institute of Forest Products concerning the use of sawdust and bark, combined with waste organic material, for soil conditioners. The quantity which could be produced appears to be limited only by the availability of organic waste, as more than 32 million cubic feet of bark and sawdust are wasted each year in the state.

Dr. Stanley P. Gessel, forester and soils expert, has been selected by the Institute's Director, Gordon D. Marckworth, to guide a two-year work project designed to utilize much of this leftover forest material. Dr. Gessel, who teaches forest soils at the University of Washington, will employ several of his advanced students as assistants.

Michigan Tech Schedules Hardwood Grading Course

A short course in hardwood lumber grading and measurement will be held at Michigan Tech's Ford Forestry Center, Alberta, Mich., August 26–30. Sponsored through the Institute of Extension Services of Michigan Tech by the Forest Products Research Division and the Ford Forestry Center, the course will be led by Erwin Gutsell, field representative at Grand Rapids for the National Hardwood Lumber Assoc. Assisting will be Carl W. Danielson of the Forest Products Research Division at Michigan Tech.

The course will include two days of informal discussion of practical application of the NHLA rule book and three days of practice in grading and measurement. Designed as a refresher for hardwood lumber graders, the course will also serve as an introduction to grading for persons manufacturing, shipping, selling, or utilizing hardwood lumber. Required for the course are a lumber scale stick and a copy of the NHLA rule book.

Enrollment will be limited to 25 and applications should be sent with the $25 fee to the Institute of Extension Services, Michigan College of Mining and Technology, Houghton, Mich.

New England Association Plans Kiln Drying Clinic

Efficiency of operation, with special reference to kiln structure and equipment, will receive emphasis at the Sixth Annual Six-Day Kiln Drying Clinic, of the New England Kiln Drying Association, Sept. 16–21, at the University of Massachusetts, Amherst. Importance of correlation of drying rates with specific uses and the elimination of degrade and stress relief will be covered in detail.

Tuition fee covering instruction and literature is $50, refundable in case unforeseen circumstances require cancellation. Total enrollment will be limited to 25. Applications should be addressed to Prof. J. Harry Rich, Secretary-Treasurer, New England Kiln Drying Assoc., Conservation Building, University of Massachusetts, Amherst, Mass.

Sawmill and Pallet Courses Announced by New York College

Two short courses, the Fourth Annual Small Sawmill Training Conference and the First Annual Conference on the Manufacturing and Distribution of Wooden Pallets, will be held at the newly dedicated Hugh P. Baker Forest Products Laboratory, State University College of Forestry at Syracuse, N. Y.

The small sawmill conference, August 28–30, will be coordinated by Prof. Kenneth C. Compton of the College's Dept. of Forest Utilization. Two small sawmills will be used for the conference, one similar to many throughout the country and the second located in Baker Laboratory.

The conference on manufacturing and distribution of wooden pallets September 10–12 has three major purposes. They are: 1) to familiarize those attending with good manufacturing, marketing, and management techniques; 2) to present latest information on overall industry problems to help eliminate obstacles to expansion of the wooden pallet industry; and 3) to furnish the basic essentials of the industry to help manufacturers and distributors meet competition within and without the wooden pallet industry.

Prof. Russell C. Deckert will serve as coordinator for the course, which will emphasize the how-to-do-it approach. Two faculty members and seven persons from the wooden pallet industry and government agencies will provide instruction. Total enrollment of 50 persons will be limited to those actively engaged in any phase of manufacturing and/or distribution of wooden pallets.

Registration fee is $20 and applications should be addressed to Forest Utilization Dept., State University College of Forestry, Syracuse 10, N.Y. Inquiries for the small sawmill training conference should be addressed to Small Sawmill Training Conference, State University College of Forestry, Syracuse 10, N. Y.

N. C. State College Planning Course in Furniture Finishing

Color control in finishing and decorative finishes on furniture will be featured topics during the eighth annual furniture finishing short course, scheduled for August 26–30 at the School of Forestry, North Carolina State College, Raleigh. Co-sponsors of the annual course are the N. C. State School of Forestry, the College Extension Division, and the Southern Furniture Manufacturers Assoc.

Designed for furniture finishing room foremen, their assistants, or su-

pervisors, the course will also cover: airless spraying, multi-colored coatings, color masking toners, reduction of over-spray, hot-lacquer coatings, finish repair and touch-up, and reduction of defects.

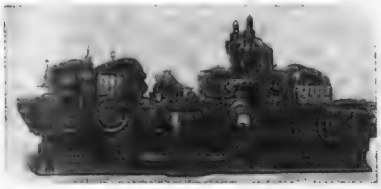
Representatives from paint, varnish, lacquer, and equipment manufacturers and distributors will assist State College staff members with demonstrations and discussions during the week-long course. Cooperating in presenting the course are 20 concerns and the National Paint, Varnish, and Lacquer Association.

Prof. Roy M. Carter, director of the course, reports that registrations will be limited to 25. Application blanks and more information may be obtained from Prof. Carter, School of Forestry, North Carolina State College, Raleigh, N. C.

NEW PRODUCTS—LITERATURE

Automatic Planer Control

A machine reportedly offering automatic precision milling of stock to close tolerances is being produced by the S. A. Woods Machine Co., Boston, Mass. It is claimed that use of the new Woods automatic hydraulic motorized top head control will hold variation of



thickness in lumber being planed to a few thousands of an inch.

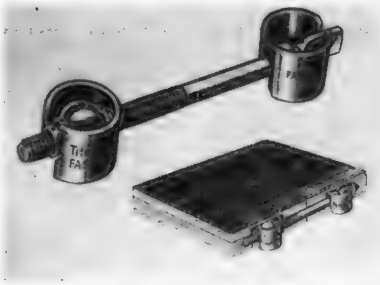
Slight deviation in thickness brings the automatic control into action. A special motor combined with constant hydraulic pressure causes the proper adjustment of top cutterhead and yoke to re-establish the original dimension.

Improved Fastener

A new bolt which permits fast installation of the Tite-Joint Fastener for assembling wood panels, laminated sink tops, counters, furniture, and other applications has been developed by E. L. Cederquist Co., Los Angeles, Calif.

The fastener distributes clamping pressure uniformly over the entire mating surfaces. Since mating pieces are drawn together internally, there is no twisting or buckling and the resulting joint is perfectly flush on both sides. This feature makes the fastener particularly suited for use with plastic laminated plywood, the manufacturer reports.

Because of the design of the fastener, extreme force can be applied in the joint. Every pound of force ex-



erted on the locking lever results in approximately 500 pounds of clamping pressures at the joint.

Laminate for Difficult Films

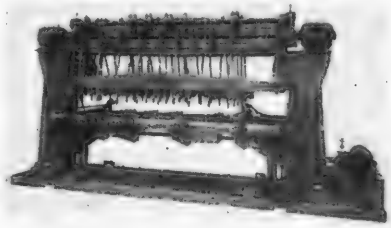
A versatile adhesive which will bond Pliofilm, Saran, and polystyrene to foil; Pliofilm to Saran and Mylar; or Mylar to Saran has been developed by National Adhesives Division, National Starch Products Inc., 270 Madison Ave., New York, N. Y. Known as Resyn 76–3963, the adhesive is a clear, amber colored synthetic rubber cement.

Containing approximately 33 per cent solids, the adhesive may be thinned with toluene or mixtures of toluene with methyl ethyl ketone or ethyl acetate. It may be applied with reverse roller or gravure coating prior to lamination. Solvent should be removed at oven temperatures of 200–250° F., and a "nip" temperature of 190° F. at 150 feet per minute is desirable when laminating film to foil or Mylar to Pliofilm or Saran. In bonding Pliofilm to Saran, a drying temperature of 125–150° F. is suitable.

Multiple Borer

A machine capable of boring up to 40 holes simultaneously in plywood panels has been designed by the B. M. Root Co., York, Pa. This new "2CXH-S4" special multiple borer, overall size of 17½ ft. x 8 ft. x 8¼ ft., is being used in the production of large plywood and gypsum board panels for prefabricated home construction.

It is reported that the machine can simultaneously bore holes in any pattern having a minimum distance of 1½ inches center to center of any two adjacent holes in a stack of panels measuring up to 10 ft. long by 4 ft. wide. It comes with a hydraulically operated table equipped with two side guides, the left one stationary and the right adjustable for various width



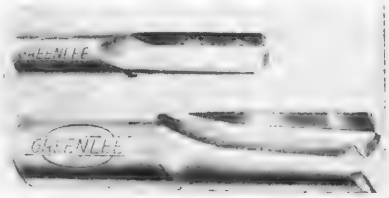
panels. Five pick-off roller brackets extend from either side of the table for infeed and outfeed of the panels.

All magnetic motor controls, push button controls, feed controls, safety switches, and control circuits are operated on 110 volts through transformers. According to the manufacturer, this machine with slight design changes can handle panels of plastic or composition material.

Carbide Router Bits

A new line of carbide tipped router bits constructed with high-speed steel bodies has been announced by Greenlee Tool Co., Rockford, Ill. The manufacturers state that the material can provide the stiffness necessary to resist vibration and breakage, and that it brazes well with carbide.

A super-hard grade of carbide is used in the bits, specially selected for the high speeds encountered in routing operations. Precision ground with the correct cutting angle, the bits reportedly permit faster, easier cutting and eliminate much of the pushing usually required. The tapered web in the flute provides extra strength and eliminates weak spots. Unusually good results were obtained on plastics, particle



board, laminated products, and other harder-than-wood materials, the manufacturer reports.

Two Laminating Bulletins

Two bulletins, one on a new hooded glue spreader and the second about rotary type laminating presses for laminating dissimilar plies, are now available from Black Brothers Co. Inc., Mendota, Ill.

The hooded glue spreader for production line lamination with solvent-type adhesives reportedly provides continuous circulation of adhesive through use of a circulating pump and adds solvent to the adhesive to replace solvent lost through evaporation.

The rotary type laminating press is suggested for use with synthetic pressure-type adhesives and to utilize structural features of dissimilar materials to achieve balanced or sandwich-like laminations. The manufacturer reports that the rotary press effects a positive bond on heavy paper, phenolic and polyester laminae, fiber board, plywood, paper honeycomb, and many other materials.

NAMES IN THE NEWS

Newly elected vice-president of the National Lumber Manufacturers Assoc. is **Mortimer B. Doyle,** until recently manager of Midwest operations of the National Association of Manufacturers. He succeeds **L. V. Bodine,** who resigned to become a vice-president of Diamond Match Co.

M. B. DOYLE

H. BAHR

Henry Bahr, veteran staff member of NLMA, has been named vice-president and general counsel. He will continue to serve as the association's secretary and director of its Law Information Service.

Robert K. Jones has been elected secretary and board member of United Wood Corp., West Memphis, Ark., according to **D. N. Copp,** president. Jones is treasurer of Wilco Machine Works, Memphis, which is engineering a new flakeboard plant for the Arkansas firm.

Verne Ketchum has been made director of engineering at Timber Structures, Inc., Portland, Ore. Succeeding him as chief engineer is **George Birkemeier,** member of the engineering department since 1946. Named development engineer with the firm was **Charles Woodworth.**

Francis H. Snyder & Associates, chemical and engineering consultants, Brookfield, Conn., have announced the appointment of **Lewis C. Wallace** as manager of development. He was formerly manager of process development with Crown Cork and Seal Co., Baltimore, Md.

Promotion of **John Meany** to Eastern field supervisor and **James Elf** to Midwest field supervisor of the firm's Structural Products Division has been announced by **James Dillon,** vice-president of National Starch Products, Inc., New York. Meany

J. MEANY

J. ELF

W. R. WARNER

M. S. HUDSON

will work out of the New York office while Elf's headquarters will be in Chicago.

W. R. Warner, manager, Southern Lumber Co., Warren, Ark., and FPRS Executive Board member, has been elected second vice-president of Southern Pine Association.

Monie S. Hudson, consulting chemist of Spartanburg, S. C., was awarded an honorary Doctor of Science degree at commencement exercises of Wofford College last month. A frequent contributor to FPRS meetings, Dr. Hudson is credited with developing the vapor drying and solvent recovery processes.

Keith C. Birdsall, assistant professor of forestry, Mississippi State College, died in May at the age of 33. A member of FPRS, he previously had served as research assistant for state agencies in Maryland, New York, and New Hampshire.

Stephen D. Pryce has been named production manager of Jens Risom Design, Inc., New York City. He was formerly quality control director, John Widdicomb Co.

EMPLOYMENT SERVICE

The FPRS Employment Service is operated without charge as a service to members. Companies or institutions with positions to be filled or individuals seeking employment may participate in this program by inserting a free ad in two consecutive issues of the FOREST PRODUCTS JOURNAL. Inquiries concerning employment listings or ads to be placed in the JOURNAL should be addressed to FPRS Employment Service, P. O. Box 2010, University Station, Madison 5, Wis. Correspondence is kept confidential.

Positions Offered

E-287—Utilization representative to assist Northeast industry on technical matters, largely consulting (with travel), limited experimental. Experience required as mechanical engineer in wood technology or management. (August)

E-288—Wood technologist for final woodwork inspector desired in Chicago area. Experienced in finishes, colors and construction of high quality musical cabinets. Able to define, detect, train and supervise personnel. Age no barrier. Experience waived in lieu of formal schooling. (August)

E-280—Graduate in wood utilization, age 25–35. To be assistant to general manager of mill making products from hard maple. Located in western Penn. Salary open. (August)

Employment Wanted

No. 421—Forest utilization graduate, age 25, married, completing 3-year tour in Air Force, desires position with private industry in western states. Experience includes logging, surveying, fire suppression, photogrammetry. Available in mid-September. (July)

No. 423—Management position desired. Mechanical and industrial design engineering education, age 37, married. Experience in furniture, cabinet, and show case mass production, including cost, time study, purchasing, labor, machine design, sales, etc. Prefer southern Calif. or northeast location. (August)

No. 424—Graduate in wood technology, age 39, married, desires position as plant manager. Experience as manager of production planning, general plant manager, technical salesman, research engineer in paper and plywood fields. (August)

No. 425—Chemical: B.Sc. and M.Sc. in chemistry desires position as co-ordinator, supervisor, or in research. Age 45, married. Experience in technical consulting to industry and chemical research. (August)

No. 426—Graduate in wood utilization, age 28, single, with experience in wood treating, research and development desires position utilizing education and experience. Prefers employment in north. (August)

No. 427—B.S. in wood utilization and M.F. in wood technology and industrial engineering, age 30, married, desires position utilizing training and experience. Experience as industrial specialist, wood engineer, quality control supervisor. Will accept employment anywhere. (August)

No. 428—Position desired as executive in research and development, or production and industrial sales. Age 49, married. Education in pre-engineering, electrical engineering and special schooling in several subjects. Experience as manager of laboratory and product development, and industrial development sales. Will accept employment anywhere. (August)

No. 429—Graduate in forest products manufacturing seeks position in field of production, management, research or teaching. Prefers general production or research connected with forest products. Age 27, married, has M.S. from College of Forestry, Syracuse, N. Y. (August)

No. 430—Graduate in wood technology, age 29, single, desires position as wood technologist. Experience as wood technologist. Prefers Pacific Coast location. (August)

No. 431—Position as wood technologist, research or development desired. Age 29, married, with M.S. in wood utilization. Experience as wood technologist, research assistant, timber sales officer. Will accept employment anywhere. (August)

No. 432—October graduate in wood technology and statistics, desires position in production, research, sales, or management. Age, 25, single. (August)

No. 433—September graduate in wood technology and statistics would like job in research, production or teaching. Age 24, single. (August)

No. 434—Position desired as plant manager, engineer, or industrial engineer. Age 40, married. B.S. degrees from University of Idaho and University of Oklahoma. Experience as production engineer, plant engineer, chief project engineer, senior design engineer, chief draftsman. Will accept employment at any location. (August)

No. 435—November graduate in utilization and marketing desires position in sales, management, production, teaching, or research. Age 26. (August)

NAMES IN THE NEWS

Newly elected vice-president of the National Lumber Manufacturers Assoc. is **Mortimer B. Doyle,** until recently manager of Midwest operations of the National Association of Manufacturers. He succeeds **L. V. Bodine,** who resigned to become a vice-president of Diamond Match Co.

M. B. DOYLE

H. BAHR

Henry Bahr, veteran staff member of NLMA, has been named vice-president and general counsel. He will continue to serve as the association's secretary and director of its Law Information Service.

Robert K. Jones has been elected secretary and board member of United Wood Corp., West Memphis, Ark., according to **D. N. Copp,** president. Jones is treasurer of Wilco Machine Works, Memphis, which is engineering a new flakeboard plant for the Arkansas firm.

Verne Ketchum has been made director of engineering at Timber Structures, Inc., Portland, Ore. Succeeding him as chief engineer is **George Birkemeier,** member of the engineering department since 1946. Named development engineer with the firm was **Charles Woodworth.**

Francis H. Snyder & Associates, chemical and engineering consultants, Brookfield, Conn., have announced the appointment of **Lewis C. Wallace** as manager of development. He was formerly manager of process development with Crown Cork and Seal Co., Baltimore, Md.

Promotion of **John Meany** to Eastern field supervisor and **James Elf** to Midwest field supervisor of the firm's Structural Products Division has been announced by **James Dillon,** vice-president of National Starch Products, Inc., New York. Meany

J. MEANY

J. ELF

W. R. WARNER

M. S. HUDSON

will work out of the New York office while Elf's headquarters will be in Chicago.

W. R. Warner, manager, Southern Lumber Co., Warren, Ark., and FPRS Executive Board member, has been elected second vice-president of Southern Pine Association.

Monie S. Hudson, consulting chemist of Spartanburg, S. C., was awarded an honorary Doctor of Science degree at commencement exercises of Wofford College last month. A frequent contributor to FPRS meetings, Dr. Hudson is credited with developing the vapor drying and solvent recovery processes.

Keith C. Birdsall, assistant professor of forestry, Mississippi State College, died in May at the age of 33. A member of FPRS, he previously had served as research assistant for state agencies in Maryland, New York, and New Hampshire.

Stephen D. Pryce has been named production manager of Jens Risom Design, Inc., New York City. He was formerly quality control director, John Widdicomb Co.

EMPLOYMENT SERVICE

The FPRS Employment Service is operated without charge as a service to members. Companies or institutions with positions to be filled or individuals seeking employment may participate in this program by inserting a free ad in two consecutive issues of the FOREST PRODUCTS JOURNAL. Inquiries concerning employment listings or ads to be placed in the JOURNAL should be addressed to FPRS Employment Service, P. O. Box 2010, University Station, Madison 5, Wis. Correspondence is kept confidential.

Positions Offered

E-287—Utilization representative to assist Northeast industry on technical matters, largely consulting (with travel), limited experimental. Experience required as mechanical engineer in wood technology or management. (August)

E-288—Wood technologist for final woodwork inspector desired in Chicago area. Experienced in finishes, colors and construction of high quality musical cabinets. Able to define, detect, train and supervise personnel. Age no barrier. Experience waived in lieu of formal schooling. (August)

E-280—Graduate in wood utilization, age 25–35. To be assistant to general manager of mill making products from hard maple. Located in western Penn. Salary open. (August)

Employment Wanted

No. 421—Forest utilization graduate, age 25, married, completing 3-year tour in Air Force, desires position with private industry in western states. Experience includes logging, surveying, fire suppression, photogrammetry. Available in mid-September. (July)

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COLD SETTING

LYTRON, LAUXEIN, RESINOX, LAUXITE: REG. U. S. PAT. OFF. *PATENT NO. 2,402,492

PROTEIN-LATEX adhesives, combinations of Lauxein caseins and Lytron latex, set at temperatures right down to freezing. With Monsanto PROTEIN-LATEX adhesives and the NO-CLAMP* process, table tops, doors and the most difficult to glue surfaces can be efficiently mass produced using shorter pressure periods and less time, space and equipment. Curing rates are easily adjusted with changes in formulation or spread rate.

PROTEIN-LATEX adhesives are easy to mix and they have a long working life. They are gap-filling, self-bonding and excellent for rough cut veneers. Bonds made with PROTEIN-LATEX adhesives are unusually durable and water resistant.

For technical data on Monsanto PROTEIN-LATEX formulations, write to Monsanto Chemical Company, Plastics Division, Room 1645, Springfield 2, Mass.

Other outstanding Monsanto Adhesives are:

LAUXITE MF-300 *A melamine adhesive for hot press, colorless waterproof bonds.*

LAUXITE 326 *A melamine-urea adhesive for hot press gluing when greater boil resistance is desired.*

LAUXITE MF-325 *A specially formulated powdered melamine resin binder for granulated wood.*

RESINOX *Phenolic resins, liquids and compounds, for granulated wood molding and hardboard.*

LAUXITE UREA *Resin glues, both liquid and powder, for high water resistant bonds.*

MONSANTO®

Southern Pine Lumber Company Becomes FPRS Supporting Member

Southern Pine Lumber Co., a 64-year-old Texas concern, has recently joined the growing list of FPRS Company Supporting Members. President Arthur Temple Jr. is the firm's designated representative to the Society.

A. TEMPLE, JR.

Mr. Temple, formerly general manager, became president of Southern Pine Lumber Co. in 1951. He is organizer and president of four companion firms, serves as an officer in eight others, and is a director in ten additional enterprises. He has served on committees and held office in several trade associations and is active in civic affairs.

Southern Pine Lumber Co. is reported to be a model of automation in the lumber industry. The mills are almost fully automatic, cutting the saw log into exact thicknesses, widths and lengths. A chain conveyor carries the lumber out of the mill to the sorters. It then moves mechanically to automatic stackers, with the stacks moving on rails into the dry kilns.

Aerial view of Southern Pine Lumber Co. plant at Diboll, Texas.

An integrated operation, the company utilizes many wood residues. The bark is used to generate power to run the mill. Slabs are cut into "squares" which are seasoned and made into mop and broom handles

Temple-White Co., a comp[illegible]ion firm, produces about one-tenth of the total handles in this country. Slabs which cannot be used for handles are processed into uniform chips for manufacture of paper or composition board.

Other products of the Diboll, Texas firm are timber, flooring, poles, piling, posts, wood parts, seats, boxes, studs, and wood flour.

Meet FPRS 100 Company Supporting Members

ALABAMA
- International Paper Co., Mobile

ARKANSAS
- The Crossett Co., Crossett
- Dierks Forests, Inc., Hot Springs
- Southern Lumber Co., Warren

CALIFORNIA
- California Redwood Association, San Francisco
- L. J. Carr & Co., Sacramento
- High Sierra Pine Mills, Inc., Oroville
- Ivory Pine Co., Dinuba
- Scott Lumber Co., Inc., Burney
- Tarter, Webster & Johnson, Stockton
- E. K. Wood Lumber Co., San Francisco

GEORGIA
- Southern Wood Preserving Co., Atlanta

IDAHO
- Boise Payette Lumber Co., Boise
- Ohio Match Co., Coeur d'Alene

ILLINOIS
- The Dean Company, Chicago
- General Electric, Ill. Cabinet Plant, Rockford
- Greenlee Tool Co., Rockford
- Edward Hines Lumber Co., Chicago
- Johnson & Carlson, Chicago
- Masonite Corp., Chicago
- Mattison Machine Works, Rockford
- Sherwin-Williams Co., Chicago
- Steger Furniture Mfg. Co., Steger

INDIANA
- The Dunbar Furniture Mfg. Co., Berne
- National Homes Corp., Lafayette
- The Wood-Worker & Veneers and Plywood, Indianapolis

KENTUCKY
- Deluxe Saw & Tool Company, Louisville

MAINE
- Moose Head Mfg. Co., Monson

MARYLAND
- J. I. Wells, Salisbury

MASSACHUSETTS
- Atlas Plywood Corp., Boston
- Draper Corp., Hopedale
- Heywood-Wakefield Co., Gardner
- A. G. Spalding & Bros., Inc., Chicopee

MICHIGAN
- Armstrong Machine Works, Three Rivers
- Baker Furniture, Inc., Grand Rapids
- The Dow Chemical Co., Midland
- Everett Piano Co., South Haven

MINNESOTA
- Mereen-Johnson Machine Co., Minneapolis
- Minnesota Mining and Mfg. Co., St. Paul
- Rilco Laminated Products, Inc., St. Paul
- Wabash Screen Door Co., Minneapolis

MISSISSIPPI
- Richton Tie and Timber Co., Richton

MISSOURI
- Monsanto Chemical Co., St. Louis

MONTANA
- Intermountain Lumber Co., Missoula

NEVADA
- Vaughn Millwork Co., Reno

NEW JERSEY
- National Adhesives, Plainfield
- Western Electric Co., Kearny

NEW YORK
- American Defibrator, Inc., New York
- Behr-Manning Corp., Troy, N. Y.
- Borden Co., New York
- Peter Cooper Corps., Gowanda
- The New Jersey Industries, Inc., New York
- Oval Wood Dish Corp., Tupper Lake
- Pierce & Stevens Chemical Corp., Buffalo
- Reichhold Chemicals, Inc., White Plains
- United States Plywood Corp., New York
- The Upson Co., Lockport

OHIO
- American Machine & Foundry Co., Shelby
- The Baldwin Piano Co., Cincinnati
- Coe Manufacturing Company, Painesville
- The Kirk & Blum Mfg. Co., Cincinnati

OREGON
- Brooks-Scanlon, Inc., Bend
- Cascades Plywood Corporation, Portland
- Forest Fiber Products Co., Forest Grove
- Mater Engineering, Corvallis
- J. Neils Lumber Co., Portland
- Oregon Lumber Co., Baker
- West Coast Lumberman's Assn., Portland

PENNSYLVANIA
- Kennametal, Inc., Latrobe
- Koppers Company, Inc., Pittsburgh
- Perkins Glue Co., Lansdale
- United States Steel Homes, Inc., Harrisburg
- Wood Metals Industries, Inc., Kreamer

SOUTH CAROLINA
- Lightsey Brothers, Miley
- Poinsett Lumber & Mfg. Co., Pickens

TENNESSEE
- E. L. Bruce Co., Memphis
- Chapman Chemical Company, Memphis
- Memphis Hardwood Flooring Co., Memphis
- Nickey Bros., Inc., Memphis

TEXAS
- Wm. Cameron & Co., Inc., Waco
- Kirby Lumber Corporation, Houston
- Love Wood Products of Texas, Diboll
- Southern Pine Lumber Co., Diboll

VERMONT
- Beecher Falls Mfg. Corp., Beecher Falls

WASHINGTON
- American Marietta Co., Seattle
- Biles Coleman Lumber Co., Omak
- Cascade Lumber Co., Yakima
- Columbia Plywood Co., Inc., Seattle
- Deer Park Pine Industry, Inc., Deer Park
- Diamond Match Co., Spokane
- Douglas Fir Plywood Association, Tacoma
- International Paper Co., Long-Bell Division, Longview
- Simpson Logging Co., Shelton
- Sumner Iron Works, Everett
- Weyerhaeuser Timber Co., Tacoma

WISCONSIN
- Harnischfeger Corp., Port Washington
- Marathon Corp., Rothschild
- Mosinee Paper Mills Co., Mosinee
- D. J. Murray Mfg. Co., Wausau
- Paine Lumber Co., Oshkosh

ALASKA
- Ketchikan Spruce Mills, Ketchikan

CANADA
- B. C. Forest Products, Ltd., Vancouver
- British Columbia Lbr. Mfrs. Assn., Vancouver
- Canadian Forest Products Limited, New Westminster, B. C.
- Dominion Electrohome Industries, Ltd., Kitchener, Ont.
- Knight Mfg. & Lbr. Co., Ltd., Meaford, Ont.
- MacMillan & Bloedel Ltd., Nanaimo, B. C.
- A. S. Nicholson & Son, Ltd., Burlington, Ont.

FPRS Forest Products Journal

Vol. VII, No. 7
July, 1957

The Application of Linear Programming to Plywood Production and Distribution[1]

JAMES S. BETHEL and CLEON HARRELL

Director, Wood Products Laboratory, and Associate Professor, Department of Economics, North Carolina State College, Raleigh, N. C.

The value of a system of linear programming in the plywood industry is discussed. Examples are cited of how such a system can be used to arrive at optimum solutions to various production and distribution problems facing management. A linear programming system is shown to provide a quantitative measure of the costs of alternative procedures.

THE OPERATOR of any manufacturing plant has at his disposal a complex of production equipment; human resources in the form of unskilled, skilled, and supervisory labor; raw material; financial resources; transportation facilities; and marketing facilities. Executive management is constantly called upon to decide how to combine these resources to manufacture and merchandise a product or group of products at a profit. The success of the firm will depend upon the skill with which its managers make these decisions. When the alternative courses of action are few, the proper decisions may be rather obvious and easy to arrive at. When they are many, the problem becomes complex and the correct course of action may be obscure. This latter situation is the one that usually prevails in the plywood industry.

A plywood plant is adaptable to the manufacture of a wide variety of grades, sizes, thicknesses, and constructions of plywood panels. The plant manager must be able to combine available log or veneer raw material, machine capacities, labor skills, and money to produce a combination of products which will yield a good profit. His goal is to combine these resources in such a way as to yield the maximum profit. The use of informal methods to reach the required management decisions usually leaves company management in doubt as to whether they have reached the best decisions. Failure to arrive at the optimum program results in the company's incurring unnecessary costs and sustaining lost profits.

Even when the skilled executives are able to reach an optimum or nearly optimum program, the intuitive method may be a costly one. In discussing a problem of arriving at the optimum program for an industrial enterprise, Henderson and Schlaifer[2] have stated that: "The few direct tests that have been made so far show that intelligent and experienced men on the job often (though by no means always) come very close to the 'best possible' solution of problems of this sort. But since problems of such complexity can almost never be handled by clerical personnel, even these good cut-and-try solutions are unsatisfactory because they take up a substantial amount of the time of supervisory employees or even of executives. The time of such men is the one thing that management cannot readily buy on the market."

New Management Tool

A new tool has been made available to industrial management which makes it possible to reduce many of these problems to a quantitative basis and to solve them mathematically. The techniques of linear programming have been successfully adapted to the answering of such management questions as:

1. What is the most profitable combination of products to manufacture in a specific production facility?
2. What is the optimum machine allocation for the manufacture of a variety of products in a single plant?
3. What is the lowest cost distribution plan for supplying a number of warehouses from several manufacturing plants?
4. Which inventory strategy is most appropriate?
5. What is the effect upon profit of changes in prices?
6. What is the best location of plants or warehouses?

As this new tool becomes more widely used and more thoroughly developed, many other uses for it are certain to be forthcoming.

The plywood company manager faces many problems requiring decisions that can be more quickly and more satisfactorily solved through the use of linear programming than through resorting to any usual procedure. For example, in a period characterized by strong markets for a wide variety of plywood products, company management must decide upon the most profitable combination of products which it can make. If good cost data are available and management is subject to no restrictions in arriving at its decision, the problem might be simply solved by selecting the product that shows the greatest difference between cost and sales price and making that product to the exclusion of all others. Unfortunately, the problem is never that simple.

The manufacturing facility which the company owns may be such that to concentrate on the most profitable item would result in the waste of a large amount of available machine time and a low total production capacity. The market condition may dictate that the sales potential for the most profitable item is not sufficiently great

[1] Presented at Session I, Quality Control, FPRS Tenth National Meeting, June 4–7, 1956, in Asheville, N. C.

The Authors: J. S. Bethel holds B.S. from U. of Washington, M.F. and D.F. degrees from Duke University. He was associated with U. S. Forest Service, Penn State College, Virginia Polytechnic Institute, and Tidewater Plywood Co. before joining N. C. State as Professor of Wood Technology in 1949. Bethel is Vice-Chairman of the Carolinas–Chesapeake Section, FPRS, and member of the Industry-Education and Quality Control Divisions.

Cleon Harrell holds B.S. and M.A. degrees from the University of Virginia. Before joining the Economics Dept. at N. C. State College, he was instructor in Statistics at the U. of Virginia and Research Associate in Agricultural Economics at the U. of Chicago.

[2] Henderson, Alexander and Robert Schlaifer. 1954. Mathematical programming. Harvard Business Review, Vol. 32, No. 3.

Table 1.—PRODUCT AND PROFIT SPECIFICATION

Product Symbol	Grade	Thickness	Construction	Profit	Profit Symbol
P_1	1-3	3/20"	3 ply	$10.13	p_1
P_2	2-3	3/20"	3 ply	15.49	p_2
P_3	1-3	¼"	3 ply	1.53	p_3
P_4	2-3	¼"	3 ply	7.15	p_4
P_5	1-3	3/8"	5 ply	5.38	p_5
P_6	2-3	3/8"	5 ply	10.68	p_6

Table 2.—OPERATIONAL RESTRICTIONS

Symbol	Nature of Restriction	Quantitative Value of Restriction
P_7	Total veneer splicer time available per day	1920 machine minutes
P_8	Total hot press time available per day	960 machine minutes
P_9	Total sander time available per day	960 machine minutes
P_{10}	Maximum amount of No. 2 grade plywood that can be sold per day	24 thousand square feet
P_{11}	Maximum amount of 3/20 inch plywood that can be sold per day	20 thousand square feet
P_{12}	Maximum amount of 3/8 inch plywood that can be sold per day	3 thousand square feet

to take the output of the plant without depressing the price. Or it may be that to sell the most profitable item the company must serve its customers by also supplying a certain amount of less profitable material. The quality of the raw material available to the company may be such as to preclude the production of just one item without excessive material waste.

For these and many other reasons, the factory management must usually plan a production program which includes several products. Where costs and market prices are known and where the restrictions imposed by technology and markets can be stated quantitatively, this kind of programming problem is usually susceptible to solution by the methods of linear programming and the profit maximizing solution rigourously determined.

As an example of such a problem, a plywood plant producing hardwood plywood panels can reasonably produce six products yielding profits as shown in Table 1. In deciding what combination of these products is most profitable to manufacture, the company management is limited by certain restrictions. Three bottleneck production operations impose technological restrictions. The market imposes three additional sales restrictions. These restrictions are listed in Table 2. The demands which each of the products makes upon the limited technological and sales resources in the manufacture of one thousand square feet of product are listed in Table 3. For the purpose of calculating the optimum combination of products to manufacture, the product processes may be expressed in terms of the limited resources in the form of a series of linear inequalities as follows:

$$
\begin{aligned}
40.67\lambda_1 + 32.67\lambda_2 + 34.67\lambda_3 + 26.67\lambda_4 + 79.14\lambda_5 + 71.14\lambda_6 &\leqq 1920\\
12.00\lambda_1 + 12.00\lambda_2 + 20.00\lambda_3 + 20.00\lambda_4 + 32.00\lambda_5 + 32.00\lambda_6 &\leqq 960\\
20.00\lambda_1 + 20.00\lambda_2 + 20.00\lambda_3 + 20.00\lambda_4 + 20.00\lambda_5 + 20.00\lambda_6 &\leqq 960\\
\lambda_2 + \qquad\qquad \lambda_4 + \qquad\qquad \lambda_6 &\leqq 24\\
\lambda_1 + \lambda_2 + &\leqq 20\\
\lambda_5 + \lambda_6 &\leqq 3
\end{aligned}
$$

These six linear inequalities may be converted into the form of linear equalities by the addition of slack or waste vectors as follows:

$$
\begin{aligned}
40.67\lambda_1 + 32.67\lambda_2 + 34.67\lambda_3 + 26.67\lambda_4 + 79.14\lambda_5 + 71.14\lambda_6 + \lambda_7 &= 1920\\
12.00\lambda_1 + 12.00\lambda_2 + 20.00\lambda_3 + 20.00\lambda_4 + 32.00\lambda_5 + 32.00\lambda_6 + \lambda_8 &= 960\\
20.00\lambda_1 + 20.00\lambda_2 + 20.00\lambda_3 + 20.00\lambda_4 + 20.00\lambda_5 + 20.00\lambda_6 + \lambda_9 &= 960\\
\lambda_2 + \qquad\qquad \lambda_4 + \qquad\qquad \lambda_6 + \lambda_{10} &= 24\\
\lambda_1 + \lambda_2 + \qquad\qquad\qquad\qquad \lambda_{11} &= 20\\
\lambda_5 + \lambda_6 + \lambda_{12} &= 3
\end{aligned}
$$

$$
\begin{aligned}
\text{Profit} &= p_1\lambda_1 + p_2\lambda_2 + p_3\lambda_3 + p_4\lambda_4 + p_5\lambda_5 + p_6\lambda_6\\
&= 10.13\lambda_1 + 15.49\lambda_2 + 1.53\lambda_3 + 7.15\lambda_4 + 5.38\lambda_5 + 10.68\lambda_6
\end{aligned}
$$

The slack or waste terms in the equations represent quantities of unused or wasted capacity. The profit function may be similarly expressed.

This series of linear equations can be solved through the use of the simplex method.[3] Table 4 illustrates symbolically the procedure for using this technique applied to a somewhat smaller problem than the one just described.

Table 5 shows the simplex solution to the plywood programming program. In the first tableau, the linear equations are set up in the form of a feasible program or basis, i.e., a production schedule which satisfies all of the technological and sales restrictions. Any feasible program may be used in the first tableau, but it is frequently convenient to use the obvious if implausible one of introducing all of the slack vectors. This has the practical meaning of wasting all of the available resources and manufacturing no product. Profit for each program corresponds to the value occurring at the intersection of column P_0 and the profit row.

This program obviously shows no profit since there is no profit associated with the slack vectors. The profit row shows these product profit factors as negative indicating that they represent only potential profits until they are introduced into the basis. Beginning with this profitless program, progress is made toward the basis yielding the maximum profit through a succession of iterations in which a new process is added to the basis to replace one previously included. In each case, the process showing the largest negative value in the profit row is included in the new basis since this represents the greatest unattained profit among the non-utilized processes and provides the best opportunity to increase profit in progressing toward the profit maximizing program.

Since one of the limitations of this mathematical technique is that there can be no more active processes than there are restrictions, it is necessary to remove one of the original processes to make room for the one coming into the basis. The process removed is the one which shows the smallest non-negative ratio of the supply of a limited resource to the demand on that limited resource made by the process being introduced.

Following the procedure illustrated in Table 4, a new tableau is prepared. This process is continued until a basis appears which yields no negative value in the profit row. When this condition occurs, the basis represents the profit maximizing solution to the problem. This is the simplex criterion.

The optimum program reached through applying the simplex technique to this problem is:

P_7—194.430 minutes per day
P_8—124.000 " "
P_3— 1.000 M sq. ft. per day
P_4— 24.000 " " " "
P_1— 20.000 " " " "
P_5— 3.000 " " " "
Profit—$391.87 per day

This is the optimum solution (profit maximizing) under the restrictions on machine time and the sales restrictions given. Products P_3, P_4, P_1, and P_5 are

[3] Charnes, A., W. W. Cooper and A. Henderson. 1953. An introduction to linear programming. John Wiley and Sons, Inc., New York.

represented in the basis and are manufactured in the quantities shown. Products P_2 and P_6 are not produced at all. It is interesting to note here that these are the two products which yield the greatest profit, and it is unlikely that any solution arrived at by the more conventional methods would leave them out of the production schedule. This can be easily demonstrated, however, that under the restrictions stated these products could be introduced into the basis only at the cost of reduced total daily profit.

It will be further noted that the available sander time has been completely exhausted under this program, but there remains unused splicer and hot press time. Additional time on these machines may be utilized to increase profits by resorting to overtime operation of the sander, providing that the additional machine time is used to increase the volume of product P_3 produced. This is the only product not subject to sales restrictions. It is also required that the additional cost of overtime on the sander does not exceed the profit on product P_3. The cost of making P_3 using overtime sander rates is increased by $.35 per thousand square feet. The profit on this item is then reduced to $1.18. P_3 can be produced at this profit rate on overtime sander operation until the remaining time on the press or the splicers is exhausted. The footage still available on these items is:

Splicer

$$\frac{194.43}{34.67} = 5.608 \text{ M sq. ft.}$$

Hot Press

$$\frac{124.00}{20.00} = 6.200 \text{ M sq. ft.}$$

It is apparent that the new limiting machines are the splicers. Accordingly, a new program can be set up which appears as follows:

P_7— 0.000
P_8—11.840
P_3— 1.000
$P_{3'}$— 5.608
P_4—24.000
P_1—20.000
P_5— 3.000
Profit—$398.49

Theoretically, the 11.84 minutes of non-utilized time on the press could be used by running a splicer overtime, providing the overtime cost of running a splicer did not exceed $1.18 per thousand square feet. However, the time involved is so short that such a refinement of the program is not worthwhile.

It is apparent that changes in the restrictions or changes in the cost or sales price of any product would necessitate a new program. To illustrate the way in which such modifications would affect the specification of an optimum program, Table 6 was constructed. This table illustrates the simplex solution to the foregoing problem assuming that the price of product P_1 was reduced by $5.00 per thousand square feet and the price of product P_3 increased by $5.00 per thousand square feet. All other prices and all costs and restrictions remain the same. The new program appears as follows:

P_7—194.430 minutes per day
P_8—124.000 " " "

Table 3.—DEMAND UPON LIMITED RESOURCES ASSOCIATED WITH THE MANUFACTURE OF 1,000 FEET OF EACH PRODUCT

Limited Resource / Product	Splicer Time P_7	Hot Press Time P_8	Sander Time P_9	No. 2 Grade Sales Limit P_{10}	3/20 Inch Sales Limit P_{11}	3/4 Inch Sales Limit P_{12}
P_1	40.67 min/M	12.00 min/M	20.00 min/M	—	1 M	—
P_2	32.67 min/M	12.00 min/M	20.00 min/M	1 M	1 M	—
P_3	34.67 min/M	20.00 min/M	20.00 min/M	—	—	—
P_4	26.67 min/M	20.00 min/M	20.00 min/M	1 M	—	—
P_5	79.14 min/M	32.00 min/M	20.00 min/M	—	—	1 M
P_6	71.14 min/M	32.00 min/M	20.00 min/M	1 M	—	1 M

Table 4.—SYMBOLIC PROCEDURE FOR SOLVING A LINEAR PROGRAMMING PROBLEM WITH THE SIMPLEX METHOD

Row	Column	A P_0	B P_4	C P_5	D P_6	E P_7	F P_8	G P_1	H P_2	J P_3	Ratio
1	P_1	A1	B1	C1	D1	E1	F1	G1	H1	J1	$\frac{A1}{H1}$
2	P_2	A2	B2	C2	D2	E2	F2	G2	H2	J2	$\frac{A2}{H2}$
3	P_7	A3	B3	C3	D3	E3	F3	G3	H3	J3	$\frac{A3}{H3}$
4	P_7	A4	B4	C4	D4	E4	F4	G4	H4	J4	$\frac{A4}{H4}$
5	P_5	A5	B5	C5	D5	E5	F5	G5	H5	J5	$\frac{A5}{H5}$
6	Profit	A6	B6	C6	D6	E6	F6	G6	H6	J6	
7	P_1	$A1 - \frac{A4}{H4}H1$	$B1 - \frac{B4}{H4}H1$	$C1 - \frac{C4}{H4}H1$	$D1 - \frac{D4}{H4}H1$	$E1 - \frac{E4}{H4}H1$	$F1 - \frac{F4}{H4}H1$	$G1 - \frac{G4}{H4}H1$	$H1 - \frac{H4}{H4}H1$	$J1 - \frac{J4}{H4}H1$	
8	P_2	$A2 - \frac{A4}{H4}H2$	$B2 - \frac{B4}{H4}H2$	$C2 - \frac{C4}{H4}H2$	$D2 - \frac{D4}{H4}H2$	$E2 - \frac{E4}{H4}H2$	$F2 - \frac{F4}{H4}H2$	$G2 - \frac{G4}{H4}H2$	$H2 - \frac{H4}{H4}H2$	$J2 - \frac{J4}{H4}H2$	
9	P_7	$A3 - \frac{A4}{H4}H3$	$B3 - \frac{B4}{H4}H3$	$C3 - \frac{C4}{H4}H3$	$D3 - \frac{D4}{H4}H3$	$E3 - \frac{E4}{H4}H3$	$F3 - \frac{F4}{H4}H3$	$G3 - \frac{G4}{H4}H3$	$H3 - \frac{H4}{H4}H3$	$J3 - \frac{J4}{H4}H3$	
10	P_2	$\frac{A4}{H4}$	$\frac{B4}{H4}$	$\frac{C4}{H4}$	$\frac{D4}{H4}$	$\frac{E4}{H4}$	$\frac{F4}{H4}$	$\frac{G4}{H4}$	$\frac{H4}{H4}$	$\frac{J4}{H4}$	
11	P_5	$A5 - \frac{A4}{H4}H5$	$B5 - \frac{B4}{H4}H5$	$C5 - \frac{C4}{H4}H5$	$D5 - \frac{D4}{H4}H5$	$E5 - \frac{E4}{H4}H5$	$F5 - \frac{F4}{H4}H5$	$G5 - \frac{G4}{H4}H5$	$H5 - \frac{H4}{H4}H5$	$J5 - \frac{J4}{H4}H5$	
12	Profit	$A6 - \frac{A4}{H4}H6$	$B6 - \frac{B4}{H4}H6$	$C6 - \frac{C4}{H4}H6$	$D6 - \frac{D4}{H4}H6$	$E6 - \frac{E4}{H4}H6$	$F6 - \frac{F4}{H4}H6$	$G6 - \frac{G4}{H4}H6$	$H6 - \frac{H4}{H4}H6$	$J6 - \frac{J4}{H4}H6$	

It is assumed that H6 is the most negative value in the Profit row of the basic feasible solution and that process P_2, therefore, comes into the new basis and that $\frac{A4}{H4}$ is the smallest positive ratio and that process P_7, therefore, comes out of the basic feasible solution to make room for P_2.

Table 5.—SIMPLEX SOLUTION TO A PLYWOOD PROGRAMMING PROBLEM

pi	Row	Column	P_0	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}	p_1 10.13 P_1	p_2 15.49 P_2	p_3 1.53 P_3	p_4 7.15 P_4	p_5 5.38 P_5	p_6 10.68 P_6	Ratio
		P_7	1920.00	1.00						40.67	32.67	34.67	26.67	79.14	71.14	58.77
		P_8	960.00		1.00					12.00	12.00	20.00	20.00	32.00	32.00	80.00
		P_9	960.00			1.00				20.00	20.00	20.00	20.00	20.00	20.00	48.00
		P_{10}	24.00				1.00				1.00		1.00		1.00	24.00
	←	P_{11}	20.00					1.00		1.00	1.00					20.00
		P_{12}	3.00						1.00					1.00	1.00	
		Profit								−10.13	−15.49	−1.53	−7.15	−5.38	−10.68	
		P_7	1266.60	1.00				−32.67		8.00		34.67	26.67	79.14	71.14	17.80
		P_8	720.00		1.00			−12.00				20.00	20.00	32.00	32.00	22.50
		P_9	560.00			1.00		−20.00				20.00	20.00	20.00	20.00	28.00
		P_{10}	4.00				1.00	−1.00		−1.00			1.00		1.00	4.00
15.49	→	P_2	20.00					1.00		1.00	1.00					
	←	P_{12}	3.00						1.00					1.00	1.00	.00
		Profit	309.80					15.49		5.36		−1.53	−7.15	−5.38	−10.68	
		P_7	1053.18	1.00				−32.67	−71.14	8.00		34.67	26.67	8.00		.49
		P_8	624.00		1.00			−12.00	−32.00			20.00	20.00			.20
		P_9	500.00			1.00		−20.00	−20.00			20.00	20.00			.00
	←	P_{10}	1.00				1.00	−1.00	−1.00	−1.00			1.00	−1.00		.00
15.49		P_2	20.00					1.00		1.00	1.00					.00
10.68	→	P_6	3.00						1.00					1.00	1.00	
		Profit	341.84					15.49	10.68	5.36		−1.53	−7.15	5.30		
		P_7	1026.51	1.00			−26.67	−6.00	−44.47	34.67		34.67		34.67		.61
		P_8	604.00		1.00		−20.00	8.00	−12.00	20.00		20.00		20.00		.20
		P_9	480.00			1.00	−20.00			20.00		20.00		20.00		.00
7.15	→	P_4	1.00				1.00	−1.00	−1.00	−1.00			1.00	−1.00		
15.49		P_2	20.00					1.00		1.00	1.00					
10.68	←	P_6	3.00						1.00					1.00	1.00	
		Profit	349.99				7.15	8.34	3.53	−1.79		−1.53		−1.85		
		P_7	922.50	1.00			−26.67	−6.00	−79.14	34.67		34.67			−34.67	.61
		P_8	544.00		1.00		−20.00	8.00	−32.00	20.00		20.00			−20.00	.20
		P_9	420.00			1.00	−20.00		−20.00	20.00		20.00			−20.00	.00
7.15		P_4	4.00				1.00	−1.00		−1.00			1.00		1.00	
15.49	←	P_2	20.00					1.00		1.00	1.00					.00
5.38	→	P_5	3.00						1.00					1.00	1.00	
		Profit	354.54				7.15	8.34	5.38	−1.79		−1.53			1.85	
		P_7	229.10	1.00			−26.67	−40.67	−79.14		−34.67	34.67			−34.67	.61
		P_8	144.00		1.00		−20.00	−12.00	−32.00		−20.00	20.00			−20.00	.20
	←	P_9	20.00			1.00	−20.00	−20.00	−20.00		−20.00	20.00			−20.00	.00
7.15		P_4	24.00				1.00				1.00		1.00		1.00	
10.13	→	P_1	20.00					1.00		1.00	1.00					
5.38		P_5	3.00						1.00					1.00	1.00	
		Profit	390.34				7.15	10.13	5.38		1.79	−1.53			1.85	
		P_7	194.43	1.00		−1.73	8.00	−6.00	−44.47							
		P_8	124.00		1.00	−1.00		8.00	−12.00							
1.53	→	P_3	1.00			.05	−1.00	−1.00	−1.00		−1.00	1.00			−1.00	
7.15		P_4	24.00				1.00				1.00		1.00		1.00	
10.13		P_1	20.00					1.00		1.00	1.00					
5.38		P_5	3.00						1.00					1.00	1.00	
		Profit	391.87			.0765	5.62	8.60	3.85		.26				.32	

Table 6.—SIMPLEX SOLUTION TO A PLYWOOD PROGRAMMING PROBLEM

pi	Row	Column	P_0	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}	p_1 5.13 P_1	p_2 15.49 P_2	p_3 6.53 P_3	p_4 7.15 P_4	p_5 5.38 P_5	p_6 10.68 P_6	Ratio
		P_7	1920.00	1.00						40.67	32.67	34.67	26.67	79.14	71.14	58.77
		P_8	960.00		1.00					12.00	12.00	20.00	20.00	32.00	32.00	80.00
		P_9	960.00			1.00				20.00	20.00	20.00	20.00	20.00	20.00	48.00
		P_{10}	24.00				1.00				1.00		1.00		1.00	24.00
	←	P_{11}	20.00					1.00		1.00	1.00					20.00
		P_{12}	3.00						1.00					1.00	1.00	
		Profit	0.00							−5.13	−15.49	−6.53	−7.15	−5.38	−10.68	
		P_7	1266.60	1.00				−32.67		8.00		34.67	26.67	79.14	71.14	17.80
		P_8	720.00		1.00			−12.00				20.00	20.00	32.00	32.00	22.50
		P_9	560.00			1.00		−20.00				20.00	20.00	20.00	20.00	28.00
		P_{10}	4.00				1.00	−1.00		−1.00			1.00		1.00	4.00
15.49	→	P_2	20.00					1.00		1.00	1.00					
	←	P_{12}	3.00						1.00					1.00	1.00	3.00
		Profit	309.80					15.49		10.36		−6.53	−7.15	−5.38	−10.68	
		P_7	1053.18	1.00				−32.67	−71.14	8.00		34.67	26.67	8.00		.49
		P_8	624.00		1.00			−12.00	−32.00			20.00	20.00			31.20
		P_9	500.00			1.00		−20.00	−20.00			20.00	20.00			25.00
	←	P_{10}	1.00				1.00	−1.00	−1.00	−1.00			1.00	−1.00		1.00
15.49		P_2	20.00					1.00		1.00	1.00					
10.68	→	P_6	3.00						1.00					1.00	1.00	
		Profit	341.84					15.49	10.68	10.36		−6.53	−7.15	5.30		
		P_7	1026.51	1.00			−26.67	−6.00	−44.47	34.67		34.67		34.67		6.61
		P_8	604.00		1.00		−20.00	8.00	−12.00	20.00		20.00		20.00		9.20
	←	P_9	480.00			1.00	−20.00			20.00		20.00		20.00		4.00
7.15	→	P_4	1.00				1.00	−1.00	−1.00	−1.00			1.00	−1.00		
15.49		P_2	20.00					1.00		1.00	1.00					
10.68		P_6	3.00						1.00					1.00	1.00	
		Profit	348.99				7.15	8.34	3.53	3.21		−6.53		−1.85		
		P_7	194.43	1.00		−1.73	−8.00	−6.00	−44.47							
		P_8	124.00		1.00	−1.00		8.00	−12.00							
6.53	→	P_3	24.00			.05	−1.00			1.00		1.00		1.00		
7.15		P_4	1.09				1.00	−1.00	−1.00	−1.00			1.00	−1.00		
15.49		P_2	20.00					1.00		1.00	1.00					
10.68		P_6	3.00						1.00					1.00	1.00	
		Profit	505.71			.3265	.62	8.34	3.53	3.32				4.68		

P_3— 24.000 M sq. ft. per day
P_4— 1.000 " " " " "
P_2— 20.000 " " " " "
P_6— 3.000 " " " " "
Profit—$505.71 per day

This program is much more profitable than the optimum program possible under the old price list. If overtime is again used on the sander to produce the unrestricted product P_3 until the splicer time is exhausted, the profit on the new program becomes $505.37.

It is apparent that linear programming provides a positive method of solving complex manufacturing problems in many variables. It is, however, not a cure-all. It is strictly applicable only to problems where costs or revenues are linearly related to the production level of the processes concerned.

Methods are rapidly being developed for solving problems where nonlinear relationships exist. If costs, prices, or restrictions introduced into the problem are unrealistic or erroneous or if real restrictions are ignored, the solution may not be reasonable. This limitation, of course, applies with equal force to any method used to arrive at a program.

Finally, when problems are so complex as to require the inclusion of many processes and restrictions, the job of computing itself may become prohibitive. Symonds[4] estimates that four hours per iteration would be required to solve a 25 by 50 matrix using a desk computer. He points out that such massive problems can be solved quickly if a high-speed computer is available. He indicates that the 25 by 50 matrix can be solved on an IBM 701 computer in approximately 30 seconds per iteration. Even where high-speed computational equipment is not available, complex problems may frequently be reduced to manageable size by combining operations, including only the most important variables, or by breaking the problem up into several smaller ones. This is the same problem that statisticians face regularly in designing experiments of reasonable dimensions.

Some special industrial problems can be solved by linear programming methods that are much simpler than the general simplex technique. An example of such a problem is one of the transportation type. A plywood company produces a plywood product in three factories and ships it to six warehouses. Given the capacities of the plants, the requirements of the warehouses, and the freight rates between plants and warehouses, what is the allocation of shipping orders among plants and warehouses that will minimize total shipping costs? Table 7 lists the monthly plant capacities, the warehouse requirements, and the appropriate freight rates.

[4] Symonds, G. H. 1955. Linear programming: the solution of refinery problems. Esso Standard Oil Co.

Table 7.—RATES, REQUIREMENTS, AND CAPACITIES

Plant / Warehouse	A	B	C	Warehouse Requirements
1	$ .67/cwt	$ .49/cwt	$ .81/cwt	1123 cwt
2	.57/cwt	.80/cwt	.78/cwt	1327 cwt
3	.81/cwt	.61/cwt	.92/cwt	1776 cwt
4	.82/cwt	.87/cwt	1.03/cwt	2144 cwt
5	.34/cwt	.55/cwt	.67/cwt	812 cwt
6	1.70/cwt	1.86/cwt	1.97/cwt	457 cwt
Plant Capacities	2768 cwt	3896 cwt	974 cwt	7639 cwt

Table 8 illustrates a starting program for the solution of this problem. This is obtained in the following way:

(a) Determine for factory A if there is any mutually preferred route, that is, warehouse which receives most cheaply from A and which A supplies most cheaply. 5-A is such a route; hence, as much as possible is shipped over this route. This maximum shipment of 812 cwt. is an amount which fills warehouse 5; this filled warehouse does not receive further consideration in determining the starting program.

(b) Route 2-A is mutually preferred with regard to the remainder of A's output. 1327 units of A's output hence go to fill warehouse 2, and this second warehouse need not be further considered. The remaining 629 units of A's output is momentarily unassigned because no mutually preferred route exists over which it may shipped.

(c) Route 1-B is mutually preferred with respect to factory B, and warehouse 1 is filled with 1123 units of B's output, thus removing the first warehouse from further immediate role in the calculations.

(d) Route 3-B is mutually preferred with respect to B, so warehouse 3 is filled with 1776 units from B. Warehouses 4 and 6 remain to be filled.

(e) Since there are no more mutually preferred routes with respect to B and C, A is reconsidered. 4-A is mutually preferred, and warehouse 4 receives the remaining 629 units of A's output. Factory A is removed from necessity of further consideration by this decision, since all of its output is assigned to warehouses.

(f) Route 4-B is now mutually preferred, and the remainder of B's output, or 998 units, is assigned to warehouse 4; factory B plays no further immediate role as all of its output is assigned to warehouses.

(g) With regard to factory C, route 4-C is mutually preferred and 517 go to complete filling warehouse 4. The remainder of the output of C goes to fill warehouse 6. It is a general characteristic of the method that the number of used routes is one less than the sum of the number of factories and the number of warehouses, in this case 8. The cost of this program of shipments is $5,482.94, found by multiplying each shipment by its appropriate freight rate and adding these costs for all shipments. The θ's appearing in Table 8 should be ignored at this time; their role in the calculations is explained later.

Table 9 is a table of revenues. These revenues have the following interpretation: If an unused route is used, certain savings can ordinarily be effected through adjustments of shipments along other routes, which is made possible by utilization of the new route. The procedure of computing these revenues assures that for each used route the revenue is equal to the freight rate, but this equality is not necessarily true of the unused routes.

Hence, there are three possible relationships between the revenues and the freight rates for any particular route: First, for all used routes the revenues and the freight rates are equal. Second, for some of the unused routes the revenues may be less than or equal to the corresponding freight rate, indicating that the saving by using this route does not exceed the freight charges such use would entail. Third, for some of the unused routes the revenues may be greater than the corresponding freight rate, indicating that the saving by bringing this route into use exceeds the freight charges such use entails. In the third case, a lower cost program may be found; this procedure of finding a lower cost program will be repeated until an optional program is obtained, at which point the second condition holds for all revenues. The

Table 8.—FIRST FEASIBLE SOLUTION

	A	B	C	Requirement
1		1123		1123
2	1327			1327
3		1776		1776
4	629−θ	998	517 θ	2144
5	812			812
6	θ		457−θ	457
Capacity	2768	3897	974	7639

C_1=$5,482.94

Table 9:—FIRST REVENUE TABLE

	A	B	C	Row Value
1	.44	.49	.65	.00
2	.57	.62	.78	.13
3	.56	.61	.77	.12
4	.82	.87	1.03	.38
5	.34	.39	.55	−.10
6	1.76	1.83	1.99	1.32
Column Value	.44	.49	.65	

table of revenues is obtained in the following way:

(a) Freight rates are filled in Table 9 corresponding to the routes which are used in the starting program shown in Table 8. These rates are underlined.

(b) The next stage is to fill in the row values and the column values shown in Table 9. The first warehouse is assigned a row value of zero; a column value for factory B is then determined such that the freight rate shown on used route 1-B is the sum of the corresponding row value and the column value. This fixes the column value for B at .49.

(c) The row value for row 3 is now determined to be .12, since .12 + .49 = .61. Further, the row value of row four is .38, since .38 + .49 = .87.

(d) The remaining column values are now determined. For column A the value is .44, since .44 + .38 = .82; and for column C the value is 65, since .65 + .38 = 1.03.

(e) The row values for rows 2, 5, and 6 are now seen to be .13, −.10, and 1.32, respectively.

(f) After completing the row and column values, the last step in preparing the table is to obtain the entry for those cells corresponding to unused routes by adding the row value for the cell to the column value for the cell. For example, the entry for unused route 3-A is .56 = .12 + .44.

That this entry of .56 indeed has an interpretation as a revenue may be seen in the following manner. Notice in Table 8 that for each unit shipped over route 3-A there must be shipped one less over route 3-B, one more over route 4-B, and one less over route 4-A. The revenue associated wth bringing route 3-A into use is computed in a straightforward manner, as each unit shipped over this route saves:

Freight cost of shipping a unit over route 3-B = ...	.61
Freight cost of shipping a unit over route 4-A = ...	.87
Total saving in freight cost	1.43

From this saving must be subtracted:

Freight cost of shipping a unit over route 4-B = ...	.87

to obtain

Net saving or revenue from utilization of route 3-A = ...	.56

It is because this revenue from utilization of 3-A is less than the cost of utilization as measured by the freight rate of .81 that the route remains unused.

The revenues for each route are now compared with the freight rates shown in Table 7. As was pointed out above, it will be possible to reduce the cost

Table 10.—SECOND FEASIBLE SOLUTION—OPTIMAL SOLUTION

	A	B	C	Requirement
1		1123		1123
2	1327-θ		θ	1327
3		1776		1776
4	172 θ	998	974-θ	2144
5	812			812
6	457			457
Capacity	2768	3897	974	7639

$C_2 = C_1 - (1.76 - 1.70)\ 457$
$= \$5,455.52$

of shipping if any revenue exceeds the corresponding freight rate. This occurs in the cell corresponding to route 6-A, indicating that this presently unused route should be brought into use. The difference in revenue and freight rate for this route indicates the saving which can be effected by shipping one unit over this route, provided appropriate adjustments are made elsewhere in the shipping schedule. This saving is 1.76 − 1.70 = .06. It will be desirable to increase shipments over this route as much as possible, as this maximizes the saving in shipping cost. This amount and the appropriate adjustments elsewhere in the program may be determined as follows:

(a) Let θ represent the amount to be shipped over route 6-A. Referring back to Table 8, a $+\theta$ is placed in the cell corresponding to the route being brought into use. This increase in shipments from factory A can only occur if shipments are reduced elsewhere, and so shipments over route 4-A are altered by an amount $-\theta$.

(b) At this stage, although factory A is back in balance, warehouse 4 is underfilled, and warehouse 6 is overfilled. This imbalance among warehouses can be rectified by increasing shipments over route 4-C and decreasing shipments over route 6-C by the amount θ. The process of indicating adjustments in the program is now complete, as all factories and warehouses are back in balance. It is necessary that θ appear alone only once, with a plus sign, in the cell corresponding to the route being introduced; further, the θ's must sum to zero in each row and column in which they appear.

Observe that these requirements determine the adjustments, e.g. although factory A could be brought into balance by decreasing shipments over route 5-A, it would then be necessary in order to get warehouse 5 back into balance to introduce the usage of a second unused route, which is not allowed by the process. Similar considerations dictate that θ be added to shipments over route 4-C rather than shipments over route 4-B.

Table 11.—SECOND REVENUE TABLE

	A	B	C	Row Value
1	.44	.49	.65	.00
2	.57	.62	.78	.13
3	.56	.61	.77	.12
4	.82	.87	1.03	.38
5	.34	.39	.55	−.10
6	1.70	1.75	1.91	1.26
Column Value	.44	.49	.65	

Table 12.—ALTERNATIVE OPTIMAL SOLUTION

	A	B	C	Requirement
1		1123		1123
2	353		974	1327
3		1776		1776
4	1146	998		2144
5	812			812
6	457			457
Capacity	2768	3897	974	7639

It is now possible to give a more detailed explanation of why .06 is saved for each unit shipped over route 6-A, provided optimal adjustments are made in the program elsewhere. For factory A, the unit cost of diverting shipments from warehouse 4 to warehouse 6 is .88. However, this permits factory C to divert shipments from warehouse 6 to warehouse 4, allowing a reduction in the cost of shipping the output of factory C by .94. Hence the net saving is .06. It is characteristic of linear programming that it examines all the interlocking parts of a problem and points out any indirect savings which may be made.

(c) The next step is to determine the physical quantity to be shipped over route 6-A, that is, to determine θ. Since shipments cannot be negative, the largest possible θ will be the smallest current shipment to which there is attached a $-\theta$. Hence, $\theta = 457$. The new shipping program is shown in Table 10. Route 6-C has been eliminated, while route 6-A has been added; the number of used routes remains 8. The cost of this program of shipments is \$5,482.94 − .06(457) = \$5,455.52, or the cost of the original program minus the saving. This cost could also be computed directly from the freight rates in Table 7 and the shipments in Table 10.

The table of revenues corresponding to the new program is computed by the method described above. Table 11 shows the results of these calculations. The program in Table 11 is now seen to be optimum, since nowhere is the revenue greater than the corresponding freight rate, and, therefore, no further savings can be made. However, the revenue and freight rate are equal for unused route 2-C. This equality for an unused route indicates the existence of an alternative optimum program in which there are shipments over the route corresponding to the equality. This alternative optimum program is determined by the method described previously, and is shown in Table 12.

From the point of view of minimizing shipping costs, one of these programs is as good as the other. However, the existence of alternative optimum programs gives management an opportunity to exercise choice if there is any advantage in doing so. If

of shipment and other aspects of freight service differ appreciably over different routes, management can use knowledge of these differences to make an appropriate choice between the optimum routes.

This problem was limited to the selection of a program for supplying a single product to a group of warehouses from several plants. Obviously, plywood factories customarily produce a variety of products and these products would be marketed through the same warehouses. Management might well decide to forego the selection of the optimum shipping program for a particular product in the interest of integrating shipments of all products to provide the best total distribution pattern. Several products would usually be combined in single car loadings, and the program selected might reflect the necessity of shipping in carload quantities. Even in these cases, the information supplied by linear programming would permit executive management to combine the products into carload lots in an optimum manner.

The transportation problem just described illustrates the application of linear programming techniques to the planning of a company's distribution system. The example given here represents a relatively simple problem. When the number of plants and warehouses is increased, the task of planning a rational distribution procedure becomes much more complex, and, accordingly, the advantages associated with the use of the linear programming approach become much greater.

The same general technique with minor modifications can be used in situations where the sales from each warehouse are specified and the determination of the production level at each plant is a part of the programming problem. Similarly, problems involving the possibility of oversupplying warehouses, analysis of the influence of price on volume, and other similar scheduling and allocation situations can be quantitatively handled with linear programming.

In all of the major areas of wood product manufacture and distribution, linear programming offers opportunities to reach management decisions quickly and with smaller expenditure of valuable executive time. The answer obtained can be relied upon to be the optimum solution to the problem as posed. While it may well be that for good and sufficient reason management may eschew the optimum solution on occasions, even under these circumstances the decision-making executives are provided with a quantitative measure of the cost of electing a sub-optimum procedure.

This discussion of the use of linear programming in the plywood industry has opened just a few doors. There are many more to be opened. The plywood industry in particular and the wood products industries generally have many unique problems requiring management decisions. Much research is needed to determine how the methods of linear programming can be applied to the solutions of these problems. All of the existing evidence suggests that such research, if properly conducted, will be fruitful and rewarding.

Discussion

H. O. Fleischer (U. S. Forest Products Laboratory): How much time is necessary to collect the basic data for setting up a program?

Dr. Bethel: That would depend upon the cost and production control information a company normally obtained as a part of its regular operations. In this case, all of the information needed for the programming problem was already being collected and it was necessary only to formulate the problem and plug in the raw data.

H. O. Fleischer: Are companies now collecting these data?

Dr. Bethel: Yes and no. Some are and some are not. This of course applies only to this particular type of programming problem. Linear programming is one of the tools of operations research and has many potential applications. For some of the applications that might be made, the data required would probably not normally be available and would have to be collected.

J. A. Christensen (Consultant): Are any allowances made for breakdowns? Have such allowances been made in this problem?

Dr. Bethel: Yes, allowances for breakdown were included in this problem. These allowances can be made by reducing the total number of machine hours available or by including an allowance for down time in the operating machine budget. The latter procedure was followed in this case.

Milton H. Mater (Mater Engineering Co.): Has this actually been done in any present plant? Could this data be put into an equation which could have price and demand factors changed as conditions warrant?

Dr. Bethel: These methods have been used in plants in other industries. As far as I know, this is the first application in the wood-using industry. The restrictions that describe market conditions and demand could be added to or changed to reflect a changing market. A new program would then be computed. This is, in fact, the way the technique would be used in practice.

R. W. Pettersen (St. Paul and Tacoma Lumber Co.): Is linear programming as useful a tool for foremen and superintendents who face a varying set of constraints both daily and by shifts, as it is to higher levels of management who are more concerned with longer-term decisions?

Dr. Bethel: Certain kinds of programming problems of concern to foremen and superintendents can be set up so that they can be rather quickly solved with simple techniques. Under these circumstances, the method is useful in making day-to-day and shift-to-shift decisions. This is a relatively new field of application and much more work needs to be done in developing suitable methods.

The more complex problems require considerable time to solve and these techniques are more useful to executive management in making longer term decisions. This is the way linear programming has been used most in the past.

Mr. Pettersen: Is your example based on actual or assumed data from a hardwood plywood mill? If based on actual data, is this mill now regularly using linear programming as a management technique?

Dr. Bethel: The production example is based upon actual data obtained from a hardwood plywood firm which I was serving as a consultant. The data were changed to conceal actual prices and costs to comply with the request of the plywood manufacturer. This modification did not change the basic problem or its solution. The technique was used to solve the problem at hand. Since the company does not have a man on its staff trained to use linear programming, it is not regularly using linear programming as a management technique. The transportation problem was a hypothetical one but was based upon actual freight rates between the assumed factory locations and warehouse locations.

Effect of Several Drying Conditions on Strength of Coast-Type Douglas-Fir Timbers

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Four-inch Douglas-fir timbers were air-dried, kiln-dried, and organic-vapor-dried. A study was made of the effect of various temperatures on drying rate, hygroscopicity, checking, and strength.

Introduction

DRYING WOOD MEMBERS of large size frequently is desirable where these members are to be used inside buildings or in other dry locations. Adequate drying prior to fabrication reduces distortion, permits better selection of material with respect to both natural and seasoning characteristics, and minimizes residual shrinkage that often necessitates additional maintenance to tighten bolted structures. Unfortunately, both air-drying and kiln-drying are time-consuming operations that frequently cannot be fitted into production schedules. A method for drying timbers rapidly would be desirable if properties of the wood are not affected seriously.

Associated Work: Previous work (2)[1] in which 4-inch Douglas-fir timbers had been dried in xylene vapors at 225° F., indicated that such material could be dried to a moisture content of 12 per cent in about 30 hours. Although no internal checks (honeycomb) were present when timbers were sectioned at completion of drying, honeycomb did develop during subsequent storage.

Objectives: Work was initiated to determine:

1. Honeycomb development in timbers dried in xylene vapors.
2. Comparative rate of kiln drying 4-inch material at 150° and 200° F.
3. Effect of various drying conditions on certain strength properties of timbers and of small, clear, specimens cut from them.

Experimental Procedure

Description of Test Material: Timbers studied were 4- by 8-inch by 10-foot, green, virtually all heart-wood, coast-type Douglas-fir. (Fig. 1). All were No. 1 common grade, meeting requirements of paragraph 204, Rule-

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[1] Numbers in parentheses refer to literature cited.

Fig. 1.—Cross sections of 4- by 8-inch timbers before testing or drying.

book 14, *Standard Grading and Dressing Rules for West Coast Lumber.* Ends of the green timbers were coated two with a urea-formaldehyde resin to minimize end drying.

A book of random numbers was used to assign each timber to one of the test series described in Table 1.

Measurements before Drying: Moisture content and specific gravity were determined for inch-long cross sections taken from ends of uncut timbers and from centers of timbers halved for kiln-drying. All moisture-content measurements were based on oven-dry weights. Specific gravity was calculated from oven-dry weights, and volumes determined by water immersion at time moisture content was determined.

Drying and Storage Conditions: Conditions for drying are summarized in Table 2. After each artificially dried series had come to about 16 per cent moisture content, the timbers were stored indoors with air-drying series A. The timbers were separated by ¾-inch stickers. All pieces were weighed frequently during drying and storage. At time of weighing, thickness and width of each piece were measured to 0.01 inch at two marked locations on each timber for shrinkage determinations.

Kiln drying. Series K1 and K2 were dried in two small, experimental, cross-circulation steam-heated dry kilns allowing a maximum usable length of 6 feet.

Drying in xylene vapors. Series VI was dried in an experimental treating plant at an average temperature of 220° F. and a vacuum of 17 inches of mercury. Liquid xylene was heated in an evaporator from which xylene vapor passed through the drying chamber to the condenser. Some xylene vapor condensed on the wood and walls of the chamber, rapidly raising the temperature to 220° F. Water vapor and excess xylene vapor were condensed and liquids collected in a separator. Water was drained periodically and weighed, while xylene drained continuously to the condensate tank, from which it was pumped to the evaporator for reuse.

Moisture Distribution Determinations: A 3-inch-long cross section was removed from near the center of each timber after full-size bending tests were completed. Moisture-content specimens 1 inch wide and ½ inch thick were cut at four depths from the surface. The ½- by 1- by 3-inch pieces were weighed, stored at 70° F. and 65 per cent relative humidity for 7-8 weeks and reweighed, then oven-dried to constant weight. Moisture-content values at time of cutting and after conditioning were calculated (Fig. 2).

Strength Tests: Full-size timbers in series G, A and V1 were tested in bending. The kiln-dried timbers had been cut in half for drying, as length capacity of the kiln used was 6 feet. These kiln-dried timbers were not tested full-size. Clear specimens 2 by 2 by 30 inches in size were cut from broken full-size timbers in series G. Since some dried timbers were broken so badly as to preclude cutting 2- by 2-inch specimens, 1- by 1- by 16-inch bending specimens and ⅝- by ⅝- by 10-inch toughness specimens were cut from them.

Full-size timbers. The 10-foot pieces were broken using third-point loading on an 8-foot span with load applied at a rate of 0.1 inch per minute.

Small, clear, specimens. The 1- by 1-inch bending specimens and ⅝- by ⅝-inch toughness specimens were cut from corners and center of each piece in the dried series. Two specimens of each size were cut from each location when possible. Corner and center locations were chosen because it was believed they would show maximum and minimum effect of drying conditions.

All small bending specimens were stored a month or longer at an equilibrium moisture content condition between 11 and 12 per cent, at 70° F. Half of these specimens were broken after this conditioning period. Remaining specimens were water-soaked under pressure prior to testing to bring them to a moisture content well above the fiber saturation point.

Bending specimens were broken on a 14-inch span with load applied at mid-point. Load application speed was 0.05 inch per minute for conditioned-only specimens, but was 0.25 inch per minute for water-soaked specimens, to speed testing.

Table 1.—DESCRIPTION OF THE 4- BY 8-INCH COAST-TYPE DOUGLAS FIR TEST SERIES

Series	Drying medium	Number of pieces	Length Feet	Initial moisture content Per cent	Specific gravity*	Summer-wood Per cent	Growth rings per inch
G	None	12	10	35	0.46	35	11
A	Air	12	10	37	.44	25	9
K2†	Kiln	12	5	34	.43	25	9
K1†	Kiln	12	5	34	.43	25	9
V1	Xylene vapors	12	10	34	.44	25	8

*Oven-dried weight, and volume at moisture content shown.
†End-matched pieces cut from 10-foot timbers.

Table 2.—DESCRIPTION OF DRYING AND STORAGE CONDITIONS AND AVERAGE MOISTURE CONTENT OF TIMBER AFTER DRYING AND STORAGE

Series	Initial Drying Conditions: Dry bulb F	Wet bulb F	Equilibrium moisture content Per cent	Drying time* Hours	Storage conditions: Temperature F	Time Days	Moisture content: After drying Per cent	After storage Per cent
A	75		7	1,512	75	100		13
K2	153	137	9	260	75	149	16	10
K1	202	186	8	164	75	151	16	10
V1	220		0	25†	75	159	16	10

*To 16 per cent moisture content on dry-weight basis.
†Includes 1-hour final vacuum period and 3-hour final steaming at 220° F.

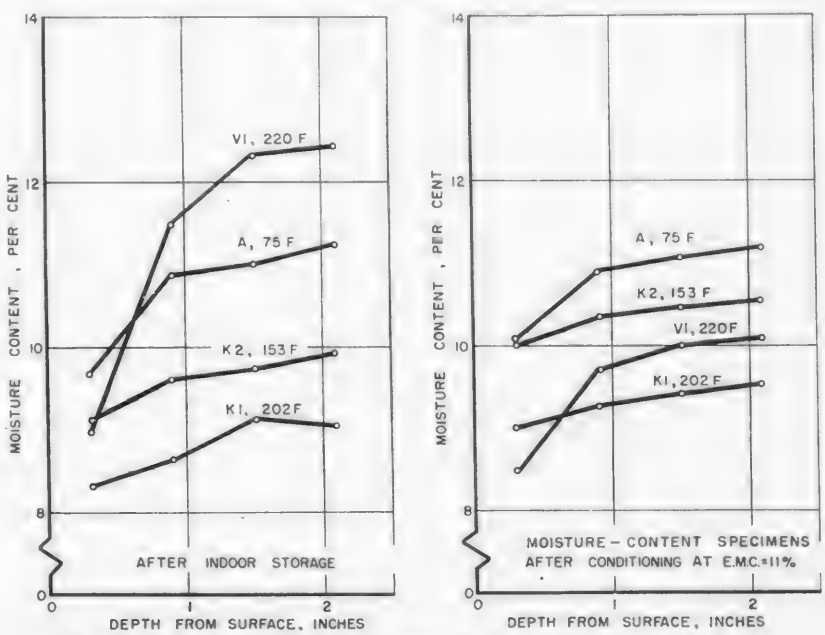

Fig. 2.—Moisture content at various depths in 4- by 8-inch Douglas-fir timbers.

Toughness tests were performed by procedure and on equipment described in Forest Products Laboratory Report No. 1308, *Forest Products Laboratory's Toughness Testing Machine.* Specimens were broken on an 8-inch span with load applied to the most nearly tangential face. Weight position 3, described in above report 1308, and initial angle of 45 degrees were used.

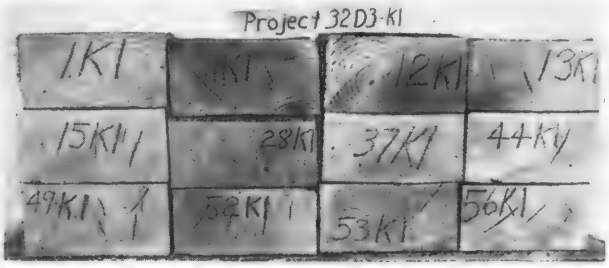

Fig. 3.—Cross sections from timbers in series K1 showing internal checks.

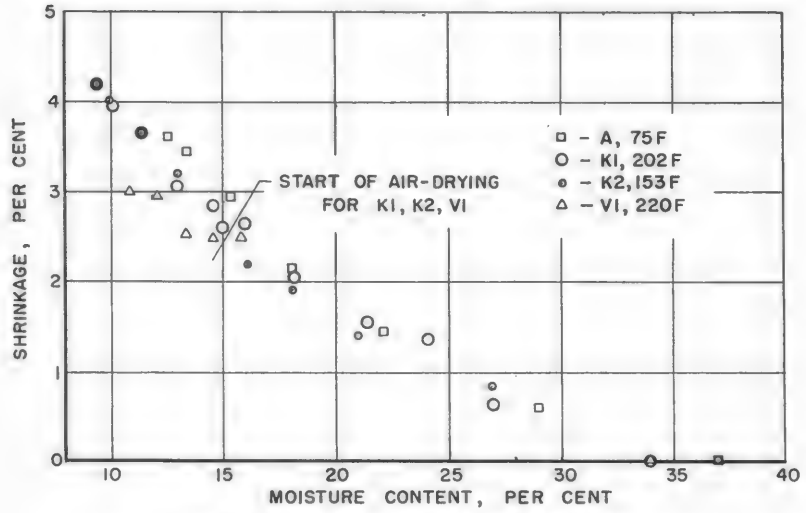

Fig. 4.—Shrinkage of Douglas-fir timbers in drying.

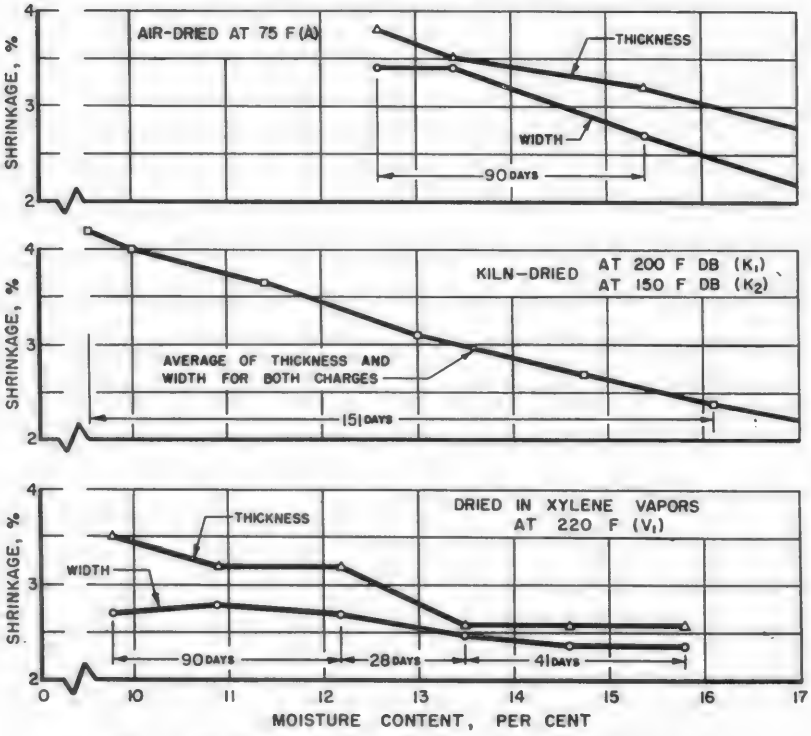

Fig. 5.—Shrinkage of Douglas-fir timbers during indoor storage after various drying treatments.

Statistical Analysis: Design of experimental work was random. Data were analyzed by analysis of variance to evaluate differences in drying conditions and location of small test specimens within large timbers. This type analysis permits evaluation of differences between average test values to determine if such differences can be expected to occur by chance, or if they probably result from treatment effects (drying condition or location in the present study). Statements of significance are made for some arbitrary level of confidence, usually 95 or 99 per cent. These levels mean that the same results could be expected 95 or 99 per cent of the time if the experiment were repeated.

When a significant difference is detected in analysis of variance, some yardstick is needed to evaluate differences between any two average test values where more than two values are involved. The least significant difference (LSD) is calculated for this purpose. Any two average values must differ by this amount before confidence can be placed in attributing difference to factors other than chance.

Coefficient of variation was calculated also for each set of test values. The coefficient is a comparative measure of variability among groups of test data. The larger the coefficient of variation, the greater the variability among groups.

RESULTS

Seasoning: *Rate of drying.* Douglas-fir timbers were dried from an initial moisture content of 34 per cent to 16 per cent in 25 hours at 220° F., in 7 days at 202° F., in 11 days at 153° F., and in 63 days of indoor air drying (Table 2). Timbers were susceptible to honeycomb when dried at 202° and 220° F. Calculated drying diffusion constants (comparative measure of drying rates) for initial drying to 16 per cent moisture content were:

Series	Temperature Deg F	Constant In²/hr
A	75	0.016
K2	153	.121
K1	202	.152
V1	220	.250

Moisture distribution. Moisture contents of specimens cut at various depths in the timbers after indoor stickered storage, and moisture contents of these same specimens after conditioning at 70° F. and 65 per cent relative humidity, are shown in Fig. 2.

After storage, average moisture content values for the different series ranged from 10 to 13 per cent. Mois-

Table 3.—BENDING TEST DATA FOR 4- BY 8-INCH DOUGLAS-FIR TIMBERS

ries	Size Inches	Drying tempera-ture F	Specific gravity*	Moisture content Per cent	Modulus of rupture Psi	Modulus of elasticity M psi	Work to maximum load In.-lb/cu in.	First break† Load Lb	First break† Deflection Inch	Load at deflection of 0.27 inch‡ Lb
C	4.11x8.25	---	0.46	33	5,310	1,350	5.36	15,380	1.47	4,500
A	4.01x8.01	75	.44	12	7,410	1,930	4.40	19,680	1.14	5,700
V	4.02x8.14	220	.44	10	3,980	1,820	2.11	9,490	0.57	5,300
L	significant difference for series A and V1									
	95 per cent level	---	----	--	1,020	215	1.79	-- ---	-- -	-----
	99 per cent level	--	-	--	1,370	287	2.39	- -		-----
C	ficient of variation									
	per cent	- --	-	- --	23.7	15	60.1		---	-----

*Oven-dry weight, green volume.
†The first break corresponds to maximum loads for series A and G.
‡Deflection of 1/360 of the span.

Table 4.—BENDING TEST DATA FOR 1- BY 1-INCH PIECES CUT FROM 4- BY 8-INCH DOUGLAS-FIR TIMBERS

ries*	Drying tempera-ture Deg F	Conditioned only: Moisture content Per cent	Specific gravity†	Mod. of rupture M psi	Mod. of elasticity M psi	Work to max. load In.-lb/cu in.	Conditioned, water-soaked: Moisture content Per cent	Mod. of rupture M psi	Mod. of elasticity M psi	Work to max. load In.-lb/cu in.
Corner										
A	75	11.3	0.487	14.2	2,125	11.98	122	7.21	1,801	8.82
K2	153	10.9	.491	13.6	2,121	10.21	134	6.66	1,780	8.63
K1	202	9.7	.506	12.9	2,058	7.54	138	6.37	1,816	5.39
V1	220	9.4	.487	12.9	2,008	9.24	137	6.38	1,639	6.86
Center										
A	75	12.0	.474	13.4	1,947	13.51	128	6.89	1,799	8.39
K2	153	11.3	.482	13.2	2,080	10.34	137	6.45	1,716	8.60
K1	202	10.2	.493	13.1	2,061	11.58	134	5.38	1,585	5.99
V1	220	11.3	.480	11.8	1,858	8.63	138	5.50	1,497	7.13
Corner and Center Combined										
A	75	11.7	.481	13.8	2,036	12.75	125	7.05	1,800	8.61
K2	153	11.1	.487	13.4	2,091	10.27	136	6.55	1,748	8.61
K1	202	10.0	.500	13.0	2,069	9.56	136	5.87	1,701	5.69
V1	220	10.2	.484	12.4	1,933	8.94	138	5.89	1,568	7.00

*There were 12 specimens from each position in each series, except for series VI, center, conditioned only, where there were only 11.
†Specific gravity based on oven-dry weight and volume at test.

ture contents in the outer 2 inches were most uniform in series K1 and K2, less uniform in series A, and least uniform in series V1. After conditioning, moisture contents for specimens cut from various depths ranged from 8.4 to 11.2 per cent.

Checking. Surface checks developed in many timbers of series A, K1, and K2 during early stages of drying, then closed during latter stages. Observations of early checking in series V1 could not be made. At end of storage, only a few pieces contained seasoning checks that were obvious. Largest checks were present in pieces where pith was near an edge or face.

Internal checks (honeycomb) were present in series K1 and V1, but were not present in series A or K2 which were dried at the lower temperatures (Fig. 3). Presence of internal checks in series V1 became apparent during bending tests when many pieces failed in shear. Honeycomb was so extensive in series K1 and V1 that considerable cutting was required to obtain small clear specimens from centers of many timbers.

The urea-formaldehyde resin used to coat timber ends proved effective in preventing development of end checks.

Shrinkage. Shrinkage of all series during initial drying, and of series A, K1, and K2 during subsequent storage, was typical of Douglas-fir (Fig. 4). Average shrinkage from 35 to 12 per cent moisture content was 3.5 per cent. Shrinkage began above an average moisture content of 30 per cent. Values for residual shrinkage may be obtained from Fig. 4 by subtracting shrinkage value for equilibrium moisture content under which wood will be used.

Shrinkage values during storage for the different series have been plotted in Fig. 5. Series K1 and K2 have been combined because of close similarity in shrinkage behavior of these two series.

During the first 40 days of storage there was little or no change in dimensions of timbers in series V1. The timbers began to shrink, and shrinkage continued until an average moisture content between 12 and 13 per cent was reached, when shrinkage virtually halted. Series K1 and K2 continued to shrink throughout the storage period.

Strength: Dried timbers, when tested in bending, ranged from 10 to 13 per cent in average moisture content. Conditioned, small, clear specimens ranged from 9 to 13 per cent. Although it is customary to correct strength values to a moisture content of 12 per cent, no corrections were made because these different moisture contents were considered a property of the wood under the test conditions.

Results of strength tests on large timbers are summarized in Table 3. Strength properties of 1- by 1-inch specimens are contained in Table 4 and the statistical analysis is summarized in Table 5. Toughness data are shown in Table 6.

Timbers. Air-dried timbers were 39 per cent higher in modulus of rupture and 43 per cent higher in modulus of elasticity than were green timbers. At a deflection of 1/360 of the span, dried timbers supported 27 per cent more load than did green pieces.

Vapor-dried timbers were significantly lower in modulus of rupture and work-to-maximum load than were air-dried timbers; there was no difference in modulus of elasticity. Although

Table 5.—STATISTICAL ANALYSIS OF SPECIMENS TESTED IN BENDING AFTER CONDITIONING AND AFTER SOAKING

Analytical item	Conditioned only: Specific gravity	Mod. of rupture	Mod. of elasticity	Work to max. load	Conditioned and soaked: Mod. of rupture	Mod. of elasticity	Work to max. load
Treatment	NS*	NS	NS	S†	S	NS	S
Position	NS	NS	NS	NS	S	S	NS
Treatment × position	NS	NS	NS	NS	NS	NS	NS
Coefficient of variation, per cent	11	17	17	39	17	19	36
Least significant difference for treatments							
95% level	——	——	——	2.34	0.62	——	1.56
99% level	——	——	——	3.10	0.82	——	2.07

*Not significantly different at the 99 per cent confidence level.
†Significantly different at the 99 per cent confidence level.

Table 6.—TOUGHNESS DATA FOR SMALL, CLEAR, 5/8- BY 5/8-INCH SPECIMENS CUT FROM CORNERS AND CENTERS OF DOUGLAS-FIR TIMBERS

Series	Test specimens: Location	Test specimens: Number	Specific gravity*	Moisture content Per cent	Toughness: Average† In.-lb.	Toughness: Minimum In.-lb	Toughness: Maximum In.-lb
A	Corner	23	0.52	11	145	39	305
K2		24	.52	12	150	44	255
K1		24	.51	10	112	68	171
V1		19	.50	10	143	51	255
A	Center	24	.51	12	133	63	232
K2		24	.50	12	151	75	223
K1		24	.52	10	160	89	238
V1		23	.49	12	142	37	249

*Oven-dry weight and volume.
†Least significant difference in toughness:
95 per cent level: 28 in.-lb
99 per cent level: not significant
Coefficient of variation: 34.2 per cent

air- and vapor-dried timbers supported similar loads at a deflection of 0.27 inch, the first break occurred at roughly twice this deflection and load in series V1 and 4 times these values in series A. This variation in ability to absorb energy was further manifested in work values, which were low for series V1.

Reductions in strength properties of vapor-dried timbers were caused by internal checks developed during drying, which led to shear failures during testing. Frequently two, and sometimes three, shear failures occurred before maximum load was reached.

Two- by two-inch green bending specimens. Average moduli of rupture and elasticity of the green specimens were slightly lower and work-to-maximum load was slightly higher than average values for Douglas-fir reported in U.S. Department of Agriculture Technical Bulletin No. 479 (4). These strength property values were:

Measurement	Present study	Bulletin 479
Moisture content, per cent	35	36
Specific gravity	0.46	0.45
Modulus of rupture, psi	7,370	7,600
Modulus of elasticity, M psi	1.470	1,550
Work-to-maximum load, in.-lb/cu in.	8.3	6.8

One- by one-inch bending specimens. Among the conditioned-only specimens, there was no significant difference in moduli of rupture or elasticity that could be attributed to drying conditions or locations of specimens. Pieces kiln-dried at 202° F. and vapor-dried at 220° F. were significantly lower in work-to-maximum load than were air-dried pieces at the 99 per cent confidence level (Tables 4, 5).

Differences in strength due to treatment and to position were detected among water-soaked specimens. Center specimens from timbers kiln-dried at 202° F. and vapor-dried at 220° F. were significantly lower than were corner specimens in moduli of rupture and elasticity. Combined values for center and corner specimens from these same series (K1 and V1) were significantly lower than were series A and K2 in modulus of rupture and work-to-maximum load.

Conditioned-only specimens from series A were 97 per cent higher in modulus of rupture and 13 per cent higher in modulus of elasticity than were water-soaked specimens from the same timbers.

Comparison of strength of large and small specimens. Strength ratios of large timbers to small clear specimens for green and air-dried material were:

Strength property	Strength ratio: Green specimens	Strength ratio: Air-dried specimens
Modulus of rupture	0.72	0.54
Modulus of elasticity	.92	.95
Work-to-maximum load	.65	.35

Development of honeycomb in vapor-dried timbers precluded comparisons with small specimens cut from them.

Strength ratios of green 2- by 2-inch specimens to water-soaked 1- by 1-inch specimens were 1.05 for modulus of rupture, 0.82 for modulus of elasticity, and 0.97 for work-to-maximum load.

Strength ratios of air-dried timbers to 2- by 2-inch, green clear specimens were 1.01 for modulus of rupture and 1.31 for modulus of elasticity.

Small, clear, toughness specimens. Corner specimens from series K1 were significantly lower in toughness than were other groups (Table 6). Average toughness value for all groups was 143 inch-pounds, which compares with 151 inch-pounds reported by Markwardt for tangential loadings (4).

Discussion of Results

Seasoning: Rapid drying in xylene vapors at 220° F. can be attributed to temperature and to very low EMC (equilibrium moisture content) conditions in the drying chamber. Development of honeycomb in vapor-dried timbers and in those kiln-dried at 202° F. and EMC conditions of 8 per cent was indicative of severity of these conditions. The kiln-drying schedule used for charge K2 (153° F. and 9 per cent EMC) also was considered severe for this size material, but excellent results obtained indicate strongly that Douglas-fir timber may be dried under such conditions and, possibly, under even more severe condition without excessive checking.

As shown in Fig. 2, specimens in high-temperature series K1 and V1 were approaching common equilibrium moisture contents during conditioning; specimens from low-temperature series A and K2 also were approaching common, but higher, equilibrium moisture contents. Since, in both groups, the series were approaching the common equilibrium moisture contents from different directions some allowance should be made for hysteresis. Such an allowance would bring the equilibrium moisture contents for series A closer to those of series K2; all but the surface specimens of series K1 would be closer to the moisture contents of similar specimens in series V1.

Hysteresis would also explain the lower moisture contents of the surface specimens from series A and K2, but it would increase the difference in the moisture contents of the surface specimens from series K1 and V1.

Drying conditions at temperatures of 202° and 220° F. did affect hygroscopicity of the wood at all depths. This effect was greatest at the surface under severe drying conditions. Prolonged exposure at 202° F. had greater effect on the center specimens than did short exposure at 220° F.

Although total shrinkage for all series was typical of Douglas-fir, shrinkage in series V1 during air storage was unusual. Absence of shrinkage during the first 41 days probably was due to adjustment of moisture content within the timbers. Rather abrupt cessation in shrinkage at a moisture content of about 12 per cent may be associated wth development of honeycomb. Absence of internal checking immediately after initial drying, which was noted in a previous study (2), indicated that this seasoning defect developed at some moisture content below 16 per cent.

Strength: Increase in strength of small, clear specimens during drying has long been recognized, but it has been assumed that gain in strength of structural members is offset by development of seasoning checks and other defects that reduce strength. This assumption was not confirmed in the present study. Air-dry timbers tested were about 40 per cent stronger in moduli of rupture and elasticity than were similar green timbers; they were also higher in these strength properties than were 2- by 2-inch clear specimens cut from green timbers. Even greater increases were found between dry, small specimens and similar water-soaked specimens cut from the

same timbers. Ratios of strength air-dry to strength wet are compared below with ratios obtained by other investigators:

Source of data	Specimen condition	Specimen size Inches	Strength ratio: Modulus of rupture	Strength ratio: Modulus of elasticity
Present study	dried; soaked	1 x 1	1.97	1.13
Markwardt (4)	green	2 x 2	1.54	1.24
Eddy (1)	green	2 x 2	1.77	1.33
Present study	green	4 x 8	1.39	1.40

Although these results indicate high grades of lumber will support loads greater than now are permitted, failure of vapor-dried timbers in shear due to presence of honeycomb emphasizes need for care in seasoning such material.

Kiln drying at a constant temperature of 150° F. and EMC condition of 8 per cent had no adverse effect on strength properties studied, indicating that this comparatively severe schedule and, quite possibly, more rapid schedules with low EMC conditions may be used without affecting strength, provided internal checking can be avoided.

At drying temperatures of 202° and 220° F., hygroscopicity of the wood was reduced. Such reductions in equilibrium moisture content of wood resulted in strength values for conditioned-only specimens that were similar to those of air-dried material. Water soaking, however, permitted detection of strength differences that were not revealed by dry specimens and, therefore, may be a more prudent testing procedure. Similar strength differences might have been detected by adjusting bending strength values of all dried specimens to 12 per cent moisture content.

Effects of temperature on wood observed in the present study have been compared in Table 7 with results obtained by MacLean from heating in water (5), steaming (6), oven-heating (7), and by Eddy from vapor drying (1). All values have been corrected to 12 per cent moisture content. MacLean used thin specimens of wood, while Eddy used 2- by 2-inch random specimens of Douglas-fir. As shown by MacLean, heating in water or steam resulted in much greater strength losses than did prolonged oven heating. Since green timbers develop a moisture gradient as soon as seasoning begins, effect on thin specimens of oven drying may be compared to drying the outer layer of wood in timbers, while steaming or heating in water may be somewhat similar to conditions existing at various depths below the surface of drying timbers.

Both MacLean and Eddy found strength properties were affected in the following order: work-to-maximum load (affected most), modulus of rupture (intermediate), and modulus of elasticity (affected least). Similar strength reductions were obtained at 250° F. by steaming, heating in water, and heating in organic vapors. Eddy found considerable reduction in work-to-maximum load at both 225° and 190° F., and some reduction in modulus of rupture at 225° F. No appreciable strength loss occurred during oven heating at 200° F. for 128 hours, although work values were lowered by heating in water at 200° F. for 60 hours.

In the present study, strength properties were affected by drying conditions in the same order as found by MacLean and Eddy. Differences in modulus of rupture were similar in magnitude to those obtained by Eddy, but work values were erratic.

Values in modulus of rupture and work-to-maximum load obtained by Eddy and by MacLean were similar. It appears, at least, that reductions in strength obtained by MacLean by heating thin specimens in water or steam before drying were not minimum reductions, as he suggests, but were nearly representative of average reductions in strength of large wood members dried at similar temperatures.

Table 7.—COMPARISON OF SOME STRENGTH PROPERTIES OF DOUGLAS-FIR HEATED UNDER VARIOUS CONDITIONS

Study	Modulus of rupture at temperatures of: 150	190-215	220-225	250	Work to maximum load at temperatures of: 150	190-215	220-225	250	Heat medium
	Per cent*				Per cent*				
MacLean (5)		92		77		80		61	Water
MacLean (6)				82				64	Steam
MacLean (7)	87	100		106		100		91	Oven
Eddy (1)		91	82	76		83	64	51	Organic vapor
Present, corner	91	85	--	--	85	63	--	--	Kiln
		--	89	--	-	--	80	--	Organic vapor
Present, center	96	91			77	86			Kiln
	--	--	86	--	--	-	63		Organic vapor

*Based on strength of air-dried controls with values corrected to 12 per cent moisture content.

Conclusions

1. Strength properties of Douglas-fir timbers were affected by high-temperature drying conditions. Timbers dried at 202° F. lost 15 per cent or more of their strength. Strength properties were affected in the following order: modulus of elasticity (affected least), modulus of rupture (intermediate), and work-to-maximum load (affected most).

2. Presence of honeycomb in timbers dried at high temperatures greatly reduced their strength and emphasized need for care in drying such material.

3. Air-dried timbers were 39 per cent stronger in bending than were similar green timbers.

4. High drying temperatures apparently lowered hygroscopicity of the wood.

5. An initial drying temperature of 150° F. was suitable for Douglas-fir timbers.

6. Kiln-drying 4-inch Douglas-fir timbers to 16 per cent moisture content required 50 per cent more time at 150° F. than was needed at 200° F.

Acknowledgments

The author expresses his appreciation to members of the Oregon Forest Products Laboratory staff and to Rhodes Cantrell of Taylor Colquitt Company who assisted in planning, executing, and reporting the project. Particular thanks is due James C. Baldwin who did most of the tedious weighing, measuring, testing, and calculating, and to John R. Stillinger for his guidance.

Special acknowledgment is due Lawrence H. Price and his company, Timber Structures, Inc., for stimulating interest in the project and contributing the timbers used.

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The Effect of Specimen Shape on the Shrinkage of Wood

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A modification has been proposed in the standard test specimen for determining shrinkage of wood, so that shrinkage in the tangential, radial, and longitudinal directions can be determined on a single specimen. Results are reported for tests comparing the proposed different-shaped specimen with standard specimens.

IT HAS BEEN SUGGESTED[1] that the standard methods for determining the shrinkage of wood[2,3] should be modified so that the shrinkage in the tangential, radial, and longitudinal directions may be determined on a single specimen. Such a change would reduce the amount of test material required and the work involved in conditioning and weighing the material as well as making it simpler to obtain truly tangential specimens. It was proposed that the test specimen should be 1 in. x 1 in. x 4 in., with the 4 in. dimension parallel to the grain, and the other dimensions in the tangential and radial directions. The standard testing procedures specify 1 in. x 1 in. x 4 in. specimens, each 4 in. in the direction of measurement. Specimens of each type are shown in Fig. 1.

In an endeavor to ascertain the effect of the proposed difference in shape on the measured shrinkage, matched specimens of each type have been prepared from each of a number of species obtained at this Laboratory for routine shrinkage tests, and the shrinkages in each of the three principal directions of each specimen have been determined. The shrinkage was measured between the green state and a nominal moisture content of 15 per cent, and the values corrected to the value at exactly 12 per cent moisture content. The specimens were open-stack air-dried from the green state, the final conditioning being carried out in an atmosphere of approximately 65 per cent relative humidity and 25° C.

Thirty-two species were represented in the tests, 23 of these being eucalypts of Australian origin, and the other 9 representing other genera from New Guinea and islands in the Western Pacific. For the eucalypt species, a total of 464 specimens were tested from 80 trees, and for the other species, 323 specimens from 57 trees. The tree mean was calculated for each type of specimen, and the species mean obtained as the mean of the tree means. The statistical analysis was carried out using these species means.

For some of the New Guinea and Pacific Island species and for two of the eucalypts it was not possible to test all three types of specimen, so that in the statistical analysis it was necessary to make adjustments to allow for the varying numbers of species. This was done using the method of analysis for double classifications[4]. The adjusted means for the shrinkages in each of the three directions for each type of specimen are shown in Table 1.

The most important results for the present purpose are the shrinkages in the tangential and radial directions, before and after reconditioning, determined using specimens 4 in. in the direction of measurement, and using specimens 4 in. along the grain and 1 in. in the direction of measurement. Comparison of these shrinkages showed the effect of specimen shape to be significant only in the case of the tangential shrinkage after reconditioning, and then only at the 5 per cent level of probability, the tangential shrinkage of the 4 in. longitudinal specimen being greater than that of the 4 in. tangential specimen. A similar difference in the tangential shrinkages was obtained before reconditioning.

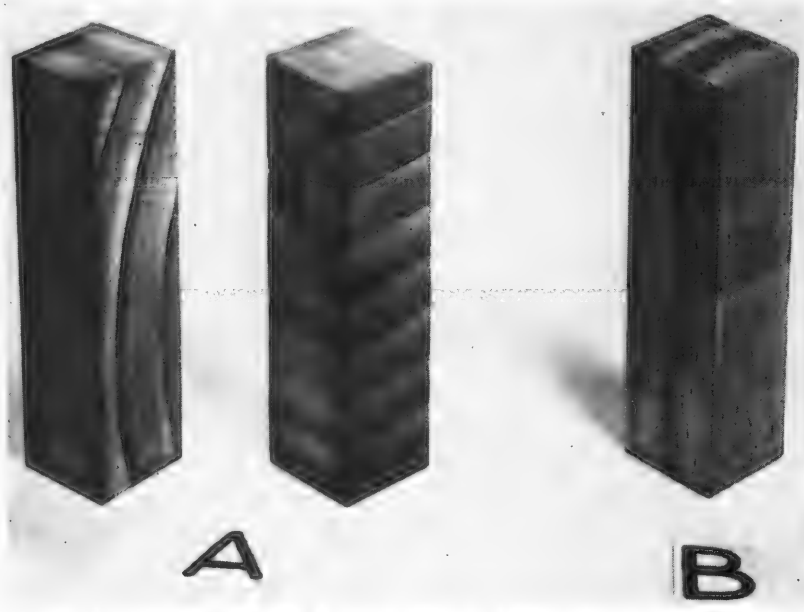

Fig. 1.—Shrinkage specimens of various types. A. Present standard test specimens. B. Proposed modified standard test specimen.

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in but it was not statistically significant. The difference is doubtless associated with the effect of the curvature of the growth rings on the measured tangential shrinkage[5], the modified procedure presumably giving a truer value than the standard method. In the radial direction no significant differences were observed.

Because the difference between the shrinkages determined on the two types of specimen is so small, modification of the standard tests as proposed is not likely to produce serious discrepancies in the comparison of the results with those obtained using the present standard test methods.

Surprising differences were obtained for the tangential shrinkage of a specimen 4 in. radially, the shrinkage before reconditioning being significantly greater (1 per cent level) than that of either of the other specimen types, and after reconditioning being significantly greater (1 per cent level) than that for a 4 in. tangential specimen, but not significantly different from that for a 4 in. longitudinal specimen.

[5] See footnote 1.

Table 1.—COMPARISON OF SHRINKAGES OF SPECIMENS OF VARIOUS SHAPES
(Adjusted Means for all Species)

Direction in which Shrinkage Measured	Dimensions of Specimen (in.)			% Shrinkage from Green to 12% Moisture Content	
	Tang.	Rad.	Long.	Before Reconditioning	After Reconditioning
Tangential	*1	1	4	9.42	5.84
	†4	1	1	9.00	5.51
	1	4	1	10.22	6.06
Radial	*1	1	4	4.50	2.94
	†1	4	1	4.30	2.84
	4	1	1	4.36	2.88
Longitudinal	*1	1	4	0.06	0.03
	4	1	1	0.08	—0.11
	1	4	1	0.06	—0.10

*Proposed modified standard test specimen.
†Present standard test specimen.

Such differences are difficult to explain, but do not affect the above conclusions as it is not proposed that such measurements should be used as standard tests.

In the longitudinal direction, a significant difference (1 per cent level) was obtained after reconditioning, the 4 in. longitudinal specimens contracting during drying, and the 1 in. longitudinal specimens of both types expanding. This difference is probably due to different drying stresses in the different types of specimen. Longitudinal shrinkage measurements are not normally included in the standard tests, their main usefulness being in the detection of the presence of reaction wood in the test sample, which would give rise to a high longitudinal shrinkage.

Acknowledgment

Grateful acknowledgment is made to Miss N. Ditchburne, Division of Mathematical Statistics, C.S.I.R.O., who was responsible for the statistical analysis of the results.

How Wood Shrinks and Swells

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Shrinking and swelling play important roles in the utilization and seasoning of wood. The mechanics of shrinking and swelling and the influence of wood structure are discussed. Emphasis is placed on the variability of shrinking and swelling, and the chief reasons for variability. The effects of shrinking and swelling on wood during seasoning and in use are discussed, along with methods of minimizing these effects.

Introduction

WOOD CHANGES IN DIMENSION as its moisture content varies. During the seasoning of green or freshly sawed lumber, there is a decrease in dimension. After the seasoned wood is put in service its dimensions decrease or increase, depending on whether it loses or gains moisture. The dimensional changes in wood are brought about by the shrinking or swelling of the cells, or fibers, of which the wood is composed. Although green wood shrinks slightly as soon as drying starts, shrinking becomes more pronounced after a certain point in drying is reached. Likewise, dry wood swells when taking on water until a certain point is reached, after which little additional swelling occurs. This point, called the fiber-saturation point, is about 30 per cent moisture content for all species of wood.

Shrinkage is the cause of most of the difficulties that arise during seasoning. Both shrinking and swelling may interfere with the most efficient utilization of wood. It is essential in the handling and use of wood, therefore, to consider the primary cause of shrinking and swelling, the shrinking and swelling characteristics of different species and types of wood, the effects of shrinking and swelling, and means by which shrinking and swelling and their effects can be minimized.

Effect of Structure of Wood Upon Shrinking and Swelling

Wood consists largely of hollow fibers or cells, most of which lie nearly parallel to the axis of the tree trunk. Chief exceptions are the wood-ray cells, which are perpendicular to the axis of the trunk. The walls of the wood cells are crystalline in structure (Fig. 1). In normal wood, most of the crystallites of the cell walls, including those of the wood-ray cells, are oriented nearly parallel to the axis of the tree trunk. The crystallites of the primary layer of the cell wall (Fig. 1) are oriented, however, so that they fall in planes perpendicular to the crystallites of the rest of the cell walls. Since the crystallites are joined end to end, they can approach or move away from each other in the lateral directions only. The crystalline structure of the cell walls, and the opposing directions of the crystallites of the primary and secondary layers of the cell walls, somewhat like cross-banded plywood, com-

[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

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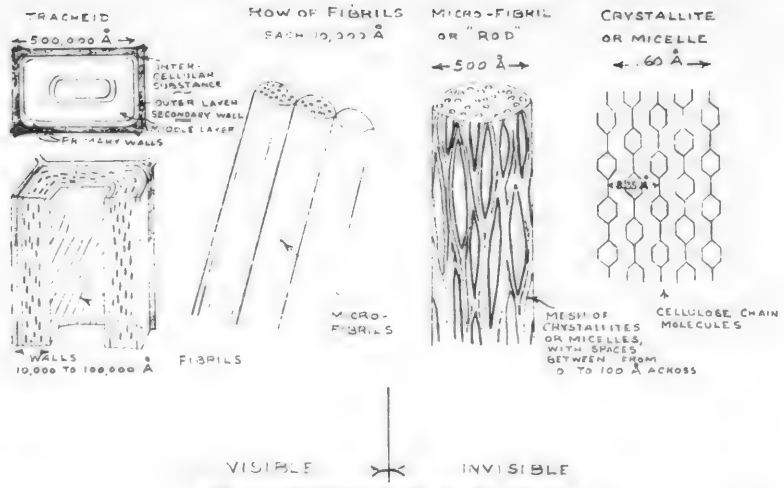

Fig. 1.—Structural details of the cell wall.

plicate the shrinkage and swelling of wood.

The open spaces, or cell cavities, within the wood cells may comprise a considerable percentage of the whole volume. For example, the cell cavities in green magnolia, a relatively lightweight wood, may equal more than 50 per cent of the total volume, while those in a heavier wood like hard maple may equal 40 per cent.

The large quantity of water that most green wood contains may be separated roughly into two parts: that contained as free water in the cell cavities and intercellular spaces of the wood, and that held as adsorbed water in the capillaries of the walls of such wood elements as fibers and ray cells. The adsorbed water, which amounts to about 30 per cent moisture content based on the oven-dry weight of the wood, is of primary interest in the consideration of shrinking and swelling, because when the amount of this water is varied, the finer wood elements approach or recede from each other and thereby cause shrinking or swelling.

The crystalline structure of the cell walls of wood and the definite orientation cause most of the shrinking and swelling to occur in a transverse plane, with respect to the axis of the tree, or in tangential and radial directions with respect to the annual growth rings. Since the crystallites of the wood-ray cells are parallel to those in the main body of cells (2, 10),[2] the wood-ray cells shrink and swell principally in the same directions as do the other cells. Although wood does not shrink and swell equally in all directions, the changes in volume could be predicted if the shrinking and swelling of the cell cavities equalled that of the cell walls.

The cell walls are composed principally of two distinct layers, an outer primary layer wrapped around a considerably thicker secondary layer. The crystallites of the secondary layer are roughly parallel to the axis of the tree, while those of the primary layer are approximately perpendicular to it. The structure of the walls of the wood-ray cells is similar, but the crystallites of the secondary layers are in planes perpendicular to the axes of the wood-ray cells, and consequently parallel to the crystallites of the secondary layers of the main wood cells. The crystallites of the primary layers of the wood-ray cell walls are roughly parallel to the long axes of the wood-ray cells. It is evident that, during shrinking or swelling, the primary and secondary walls oppose each other, and the cell cavity therefore does not change in volume like the cell walls. It is also evident that the resistance of the primary walls must be overcome before the shrinking of the secondary walls can accomplish transverse shrinkage of the wood.

Numerous experimenters (1, 9, 12, and 14) have found that the cell-cavity volume tends to remain constant with shrinking or swelling of the cell walls. On this basis, the external shrinkage or swelling of a piece of wood can be determined by its specific gravity and fiber-saturation point. The equation, according to Stamm and Loughborough (13, 15), is

$$S = df$$

in which S is the per cent shrinkage from the green to the oven-dry condition, d is the specific gravity of the wood on a dry-weight, green-volume basis, and f is the fiber-saturation point of the wood expressed as the volume of water per unit weight of the wood (in per cent), rather than the common basis of weight of water per unit weight of wood. If the fiber-saturation point is taken to be 30 per cent on a weight basis, equivalent f values of 27 per cent for hardwoods and 28 per cent for softwoods are derived for use in the formula, from Stamm's values of 1.115 and 1.071 for the specific gravity of water compressed between the crystallites in hardwoods and softwoods.

The changes in volume of the cell walls bring about changes in the overall dimensions of the piece of wood, thereby causing the wood to shrink or swell. This process is not a simple one, however, because of the presence of the cell cavities. The volume of the cell cavities may decrease, increase, or remain constant during changes in moisture content, and thus alter the relationship between changes in volume of the cell walls and changes in volume of the piece of wood as a whole.

How Wood Shrinks

When a piece of wood of any appreciable thickness dries, gradients of moisture content are established. That is, surface portions that are exposed to the drying atmosphere become dry before the interior portions. When the moisture content of any portion of the wood falls below 30 per cent, its cell walls shrink and tend to reduce the overall dimension of that portion. Since the relatively dry surfaces are intergrown with the wetter interior parts, however, they are prevented from attaining their full shrinkage. As a result, tensile stresses are set up in the dry surface zones and compressive stresses in the wet interior parts. During this stage, the overall dimensions of the piece decrease slightly, because the dry surface zones shrink and the wet interior is compressed. The tensile stresses in the surface zones, and the compressive stresses in the wet interior, may cause the wood to deform more or less permanently. These deformations, called tension and compression set, complicate shrinkage. Because of set, the tensile stress that was in the surface zones at the start of drying moves progressively inward as drying progresses. At some intermediate stage in drying, both the wet interior and the dry surfaces are in compression. In the final stages of drying, the interior is in tension and the rest of the piece is in compression.

The character of the moisture-content gradients, and the consequent stress patterns set up during drying, depend on the boundary moisture content conditions, the shrinkage coefficients of the wood, the ease with which the moisture moves through the wood, and the strength properties of the wood in compression and tension perpendicular to the grain. Strength properties are further affected by temperature and moisture content, and the effects vary with species. It is clear that the overall shrinkage of a piece of wood is influenced by the condi-

[2] Numbers in parentheses refer to literature cited.

Table 1.—SHRINKAGE VALUES OF WOOD BASED ON ITS DIMENSIONS WHEN GREEN

Species	Shrinkage								
	Dried to 20 percent moisture content[1]			Dried to 6 percent moisture content[2]			Dried to 0 percent moisture content		
	Radial	Tangential	Volumetric	Radial	Tangential	Volumetric	Radial	Tangential	Volumetric
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
SOFTWOODS									
Baldcypress (Taxodium distichum)	1.3	2.1	3.5	3.0	5.0	8.4	3.8	6.2	10.5
Cedar:									
Alaska- (Chamaecyparis nootkatensis)	.9	2.0	3.1	2.2	4.8	7.4	2.8	6.0	9.2
Atlantic white- (Chamaecyparis thyoides)	1.0	1.8	2.9	2.3	4.3	7.0	2.9	5.4	8.8
Incense- (Libocedrus decurrens)	1.1	1.7	2.5	2.6	4.2	6.1	3.3	5.2	7.6
Eastern redcedar (Juniperus virginiana)	1.0	1.6	2.6	2.5	3.8	6.2	3.1	4.7	7.8
Northern white- (Thuja occidentalis)	.7	1.6	2.4	1.8	3.9	5.8	2.2	4.9	7.2
Port-Orford- (Chamaecyparis lawsoniana)	1.5	2.3	3.4	3.7	5.5	8.1	4.6	6.9	10.1
Western redcedar (Thuja plicata)	.8	1.7	2.3	1.9	4.0	5.4	2.4	5.0	6.8
Douglas-fir (Pseudotsuga taxifolia):									
Coast type	1.7	2.6	3.9	4.0	6.2	9.4	5.0	7.8	11.8
Intermediate type	1.4	2.5	3.6	3.3	6.1	8.7	4.1	7.6	10.9
Rocky Mountain type	1.2	2.1	3.5	2.9	5.0	8.5	3.6	6.2	10.6
Fir:									
Subalpine (Abies lasiocarpa)	.9	2.5	3.1	2.1	5.9	7.5	2.6	7.4	9.4
Balsam (Abies balsamea)	1.0	2.3	3.7	2.3	5.5	9.0	2.9	6.9	11.2
Corkbark (Abies lasiocarpa arizonica)	.9	2.5	3.0	2.2	5.9	7.2	2.8	7.4	9.0
Grand (Abies grandis)	1.1	2.5	3.7	2.7	6.0	8.8	3.4	7.5	11.0
Noble (Abies procera)	1.5	2.7	4.6	3.6	6.6	11.0	4.5	8.2	13.8
Pacific silver (Abies amabilis)	1.5	3.3	4.6	3.7	7.8	11.0	4.6	9.8	13.8
California red (Abies magnifica)	1.3	2.4	4.1	3.2	5.8	9.8	4.0	7.2	12.2
White (Abies concolor)	1.1	2.4	3.3	2.6	5.7	7.8	3.2	7.1	9.8
Hemlock:									
Eastern (Tsuga canadensis)	1.0	2.3	3.2	2.4	5.4	7.8	3.0	6.8	9.7
Western (Tsuga heterophylla)	1.4	2.6	4.0	3.4	6.3	9.5	4.3	7.9	11.9
Larch, western (Larix occidentalis)	1.4	2.7	4.4	3.4	6.5	10.6	4.2	8.1	13.2
Pine:									
Eastern white (Pinus strobus)	.8	2.0	2.7	1.8	4.8	6.6	2.3	6.0	8.2
Jeffrey (Pinus jeffreyi)	1.5	2.2	3.3	3.5	5.4	7.9	4.4	6.7	9.9
Limber (Pinus flexilis)	.8	1.7	2.7	1.9	4.1	6.6	2.4	5.1	8.2
Lodgepole (Pinus contorta)	1.5	2.2	3.8	3.6	5.4	9.2	4.5	6.7	11.5
Table-mountain (Pinus pungens)	1.1	2.3	3.6	2.7	5.4	8.7	3.4	6.8	10.9
Ponderosa (Pinus ponderosa)	1.3	2.1	3.2	3.1	5.0	7.7	3.9	6.3	9.6
Red (Pinus resinosa)	1.5	2.4	3.8	3.7	5.8	9.2	4.6	7.2	11.5
Southern yellow:									
Loblolly (Pinus taeda)	1.6	2.5	4.1	3.8	5.9	9.8	4.8	7.4	12.3
Longleaf (Pinus palustris)	1.7	2.5	4.1	4.1	6.0	9.8	5.1	7.5	12.2
Pitch (Pinus rigida)	1.3	2.4	3.6	3.2	5.7	8.7	4.0	7.1	10.9
Pond (Pinus rigida serotina)	1.7	2.4	3.7	4.1	5.7	9.0	5.1	7.1	11.2
Shortleaf (Pinus echinata)	1.5	2.6	4.1	3.5	6.2	9.8	4.4	7.7	12.3
Slash (Pinus elliottii)	1.8	2.6	4.1	4.4	6.2	9.8	5.5	7.8	12.2
Sugar (Pinus lambertiana)	1.0	1.9	2.6	2.3	4.5	6.3	2.9	5.6	7.9
Western white (Pinus monticola)	1.4	2.5	3.9	3.3	5.9	9.4	4.1	7.4	11.8
Pinyon (Pinus edulis)	1.5	1.7	3.3	3.7	4.2	7.9	4.6	5.2	9.9
Redwood (Sequoia sempervirens):									
Old-growth	.9	1.5	2.3	2.1	3.5	5.4	2.6	4.4	6.8
Second-growth	.7	1.6	2.4	1.8	3.9	5.7	2.2	4.9	7.1
Spruce:									
Black (Picea mariana)	1.4	2.3	3.8	3.3	5.4	9.0	4.1	6.8	11.3
Engelmann (Picea engelmannii)	1.1	2.2	3.5	2.7	5.3	8.3	3.4	6.6	10.4
Red (Picea rubens)	1.3	2.6	3.9	3.0	6.2	9.4	3.8	7.8	11.8
Sitka (Picea sitchensis)	1.4	2.5	3.8	3.4	6.0	9.2	4.3	7.5	11.5
Tamarack (Larix laricina)	1.2	2.5	4.5	3.0	5.9	10.9	3.7	7.4	13.7
Yew, Pacific (Taxus brevifolia)	1.3	1.8	3.2	3.2	4.3	7.8	4.0	5.4	9.7
HARDWOODS									
Alder, red (Alnus rubra)	1.5	2.4	4.2	3.5	5.8	10.1	4.4	7.3	12.7
Apple (Malus sp.)	2.0	3.5	6.1	4.7	8.4	14.7	5.9	10.5	18.4
Ash:									
Biltmore, white (Fraxinus biltmoreana)	1.4	2.3	4.2	3.4	5.5	10.1	4.2	6.9	12.6
Black (Fraxinus nigra)	1.7	2.6	5.1	4.0	6.2	12.2	5.0	7.8	15.2
Blue (Fraxinus quadrangulata)	1.3	2.2	3.9	3.1	5.2	9.4	3.9	6.5	11.7
Green (Fraxinus pennsylvanica)	1.5	2.4	4.2	3.7	5.7	10.0	4.6	7.1	12.5
Oregon (Fraxinus oregona)	1.4	2.7	4.4	3.3	6.5	10.6	4.1	8.1	13.2
Pumpkin (Fraxinus profunda)	1.2	2.1	4.0	3.0	5.0	9.6	3.7	6.3	12.0
White (Fraxinus americana)	1.6	2.6	4.5	3.8	6.2	10.7	4.8	7.8	13.4
Aspen:									
Quaking (Populus tremuloides)	1.2	2.2	3.8	2.8	5.4	9.2	3.5	6.7	11.5
Bigtooth (Populus grandidentata)	1.1	2.6	3.9	2.6	6.3	9.4	3.3	7.9	11.8

(CONTINUED)

Table 1.—SHRINKAGE VALUES OF WOOD BASED ON ITS DIMENSIONS WHEN GREEN (CONTINUED)

Species	Shrinkage								
	Dried to 20 percent moisture content[1]			Dried to 6 percent moisture content[2]			Dried to 0 percent moisture content		
	Radial	Tangential	Volumetric	Radial	Tangential	Volumetric	Radial	Tangential	Volumetric
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
HARDWOODS									
Basswood, American (Tilia americana)	2.2	3.1	5.3	5.3	7.4	12.6	6.6	9.3	15.8
Beech (Fagus grandifolia)	1.7	3.7	5.4	4.1	8.8	13.0	5.1	11.0	16.3
Birch:									
Alaska (Betula papyrifera neoalaskana)	2.2	3.3	5.6	5.2	7.9	13.4	6.5	9.9	16.7
Gray (Betula populifolia)	1.7	.....	4.9	4.2	.....	11.8	5.2	.....	14.7
Paper (Betula papyrifera)	2.1	2.9	5.4	5.0	6.9	13.0	6.3	8.6	16.2
Sweet (Betula lenta)	2.2	2.8	5.2	5.2	6.8	12.5	6.5	8.5	15.6
Yellow (Betula alleghaniensis)	2.4	3.1	5.6	5.8	7.4	13.4	7.2	9.2	16.7
Buckeye, yellow (Aesculus octandra)	1.2	2.7	4.2	2.9	6.5	10.0	3.6	8.1	12.5
Butternut (Juglans cinera)	1.1	2.1	3.5	2.7	5.1	8.5	3.4	6.4	10.6
Catalpa, northern (Catalpa speciosa)	.8	1.6	2.4	2.0	3.9	5.8	2.5	4.9	7.3
Cherry:									
Black (Prunus serotina)	1.2	2.4	3.8	3.0	5.7	9.2	3.7	7.1	11.5
Pin (Prunus pennsylvanica)	.9	3.4	4.3	2.2	8.2	10.2	2.8	10.3	12.8
Chestnut (Castanea dentata)	1.1	2.2	3.9	2.7	5.4	9.3	3.4	6.7	11.6
Cottonwood:									
Eastern and southern (Populus deltoides and Populus deltoides virginiana)	1.3	3.1	4.7	3.1	7.4	11.3	3.9	9.2	14.1
Northern black (Populus trichocarpa hastata)	1.2	2.9	4.1	2.9	6.9	9.9	3.6	8.6	12.4
Cucumbertree (Magnolia acuminata)	1.7	2.9	4.5	4.2	7.0	10.9	5.2	8.8	13.6
Dogwood, flowering (Cornus florida)	2.5	3.9	6.9	5.9	9.4	16.6	7.4	11.8	20.8
Elm:									
American (Ulmus americana)	1.4	3.2	4.9	3.4	7.6	11.7	4.2	9.5	14.6
Rock (Ulmus thomasii)	1.6	2.7	4.7	3.8	6.5	11.3	4.8	8.1	14.1
Slippery (Ulmus rubra)	1.6	3.0	4.6	3.9	7.1	11.0	4.9	8.9	13.8
Greenheart (Ocotea rodiaei)	1.1	1.4	2.7	2.7	3.4	6.4	3.4	4.2	8.0
Hackberry (Celtis occidentalis)	1.6	3.0	5.6	3.8	7.1	13.5	4.8	8.9	16.9
Hickory:									
Pecan (Carya cordiformis, Carya aquatica, Carya myristicaeformis and Carya illinoensis)	1.6	3.0	4.5	3.9	7.1	10.9	4.9	8.9	13.6
True:									
Shellbark (Carya laciniosa)	2.5	4.2	6.4	6.1	10.1	15.4	7.6	12.6	19.2
Mockernut (Carya tomentosa)	2.6	3.7	6.0	6.2	8.8	14.3	7.8	11.0	17.9
Pignut (Carya glabra)	2.4	3.8	6.0	5.8	9.2	14.3	7.2	11.5	17.9
Shagbark (Carya ovata)	2.3	3.3	5.6	5.6	8.0	13.4	7.0	10.0	16.7
Holly, American (Ilex opaca)	1.6	3.3	5.6	3.8	7.9	13.5	4.8	9.9	16.9
Honeylocust (Gleditsia triacanthos)	1.4	2.2	3.6	3.4	5.3	8.6	4.2	6.6	10.8
Hophornbeam, eastern (Ostrya virginiana)	2.8	3.3	6.5	6.8	8.0	15.5	8.5	10.0	19.4
Iroko (Chlorophora excelsa)	1.1	1.6	2.8	2.7	3.8	6.8	3.4	4.8	8.5
Ironbark, gray (Eucalyptus paniculata)	1.9	2.8	4.7	4.5	6.7	11.2	5.6	8.4	14.0
Khaya (African mahogany) (Khaya sp.)	1.4	1.9	2.9	3.3	4.6	7.0	4.1	5.8	8.8
Lauan, red (Shorea negrosensis)	1.1	2.7	3.9	2.6	6.4	9.4	3.3	8.0	11.7
Laurel, California- (Umbellularia californica)	1.0	2.8	4.1	2.3	6.8	9.9	2.9	8.5	12.4
Locust, black (Robinia pseudoacacia)	1.5	2.4	3.4	3.7	5.8	8.2	4.6	7.2	10.2
Madrone, Pacific (Arbutus menziesii)	1.9	4.1	6.0	4.5	9.9	14.5	5.6	12.4	18.1
Magnolia, southern (Magnolia grandiflora)	1.8	2.2	4.1	4.3	5.3	9.8	5.4	6.6	12.3
Mahogany (Swietenia macrophylla)	1.2	1.7	2.7	2.9	4.0	6.4	3.6	5.0	8.0
Mangrove (Rhizophora mangle)	1.8	.....	5.3	4.3	.....	12.6	5.4	.....	15.8
Maple:									
Bigleaf (Acer macrophyllum)	1.2	2.4	3.9	3.0	5.7	9.3	3.7	7.1	11.6
Black (Acer nigrum)	1.6	3.1	4.7	3.8	7.4	11.2	4.8	9.2	14.0
Red (Acer rubrum)	1.3	2.7	4.4	3.2	6.6	10.5	4.0	8.2	13.1
Silver (Acer saccharinum)	1.0	2.4	4.0	2.4	5.8	9.6	3.0	7.2	12.0
Sugar (Acer saccharum)	1.6	3.2	5.0	3.9	7.6	11.9	4.9	9.5	14.9
Oak:									
Black (Quercus velutina)	1.5	3.2	4.7	3.6	7.8	11.4	4.5	9.7	14.2
Bur (Quercus macrocarpa)	1.5	2.9	4.2	3.5	7.0	10.2	4.4	8.8	12.7

tion under which it is dried, and that the primary shrinkage of the cell walls may set in operation a series of stresses that, in combination with the resistance offered by the wood, determine the overall change in dimensions.

Variability of Shrinkage

One of the prominent things about shrinkage is its variability. Shrinkage not only differs among the three directions of grain, tangential, radial, and longitudinal, but also among species. Table 1 gives shrinkage values determined at the Forest Products Laboratory for the wood of numerous species. Values for longitudinal shrinkage are not given because they are usually slight.

Hardwoods shrink considerably more than softwoods. Tangential shrinkage is greater than radial shrinkage, but the ratio between the two varies greatly. Also, woods with a high specific gravity generally shrink the most. Basswood, a light wood, has high shrinkage, however, while black locust, a heavy wood, has moderate shrinkage.

Shrinkage varies widely in material cut from the same species, and even in material cut from the same tree (Figs. 2 and 3). Sapwood generally shrinks less than heartwood. The springwood of an annual ring shrinks less transversely and more longitudinally than the summerwood of the same ring.

Why wood shrinks more tangentially than radially has never been explained satisfactorily. It was thought that the wood-ray cells restricted radial shrinkage because the length of the wood-ray cells lies in a radial direction. It has been found, however, that the structure of the wood-ray cells permits large lengthwise shrinkage (10, 11).

Although the wood-ray cells shrink more lengthwise than the adjacent cells, this shrinkage is less than the radial shrinkage of the other cells (3, 4, 5, and 6). Consequently, the wood-ray cells exert a restraining effect on radial shrinkage. Morschauser (6) isolated the broad rays of red oak and found a relative density factor of 0.76 compared with 1/14 for the other wood fibers. This low density and consequent weakness would tend to diminish the effect of the wood-ray cells in restraining radial shrinkage.

The difference between tangential and radial shrinkage may be caused by the inflection of the crystallites near the pits, since they occur on the radial faces of the wood fibers only (10), or by the position of the bands of

Table 1.—SHRINKAGE VALUES OF WOOD BASED ON ITS DIMENSIONS WHEN GREEN (CONTINUED)

Species	Shrinkage								
	Dried to 20 percent moisture content[1]			Dried to 6 percent moisture content[2]			Dried to 0 percent moisture content		
	Radial	Tangential	Volumetric	Radial	Tangential	Volumetric	Radial	Tangential	Volumetric
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
HARDWOODS									
Oak:									
California black (Quercus kelloggii)	1.2	2.2	4.0	2.9	5.3	9.7	3.6	6.6	12.1
Canyon live (Quercus chrysolepis)	1.8	3.2	5.4	4.3	7.6	13.0	5.4	9.5	16.2
Chestnut (Quercus prinus)	1.8	3.2	5.6	4.4	7.8	13.4	5.5	9.7	16.7
Laurel (Quercus laurifolia)	1.3	3.3	6.3	3.2	7.9	15.2	4.0	9.9	19.
Live (Quercus virginiana)	2.2	3.2	4.9	5.3	7.6	11.8	6.6	9.5	14.7
Oregon white (Quercus garryana)	1.4	3.0	4.5	3.4	7.2	10.7	4.2	9.0	13.4
Pin (Quercus palustris)	1.4	3.2	4.8	3.4	7.6	11.6	4.3	9.5	14.5
Post (Quercus stellata)	1.8	3.3	5.4	4.3	7.8	13.0	5.4	9.8	16.2
Northern red (Quercus rubra)	1.3	2.7	4.5	3.2	6.6	10.8	4.0	8.2	13.
Rocky Mountain white (Quercus utahensis)	1.4	2.4	4.2	3.3	5.8	10.0	4.1	7.2	12.5
Scarlet (Quercus coccinea)	1.5	3.2	4.6	3.7	7.8	11.0	4.6	9.7	13.8
Southern red (Quercus falcata)	1.5	2.9	5.4	3.6	7.0	13.0	4.5	8.7	16.3
Swamp chestnut (Quercus michauxii)	1.7	3.6	5.5	4.2	8.6	13.1	5.2	10.8	16.4
Swamp white (Quercus bicolor)	1.8	3.5	5.9	4.4	8.5	14.2	5.5	10.6	17.7
Water (Quercus nigra)	1.4	3.1	5.5	3.4	7.4	13.1	4.2	9.3	16.4
White (Quercus alba)	1.8	3.0	5.3	4.2	7.2	12.6	5.3	9.0	15.8
Willow (Quercus phellos)	1.7	3.2	6.3	4.0	7.7	15.1	5.0	9.6	18.9
Osage-orange (Maclura pomifera)			5.1			7.4			9.2
Persimmon, common (Diospyros virginiana)	2.6	3.7	6.4	6.3	9.0	15.3	7.9	11.2	19.1
Sassafras (Sassafras albidum)	1.3	2.1	3.4	3.2	5.0	8.2	4.0	6.2	10.3
Sweetgum (Liquidambar styraciflua)	1.7	3.3	5.0	4.2	7.9	12.0	5.2	9.9	15.
Sycamore, American (Platanus occidentalis)	1.7	2.5	4.7	4.1	6.1	11.4	5.1	7.9	14.2
Tanguile (Shorea polysperma)	1.4	3.0	4.4	3.4	7.3	10.6	4.3	9.1	13.3
Teak (Tectonia grandis)	.8	1.4	2.3	1.8	3.4	5.4	2.3	4.2	6.7
Tupelo:									
Black (Nyssa sylvatica)	1.5	2.6	4.6	3.5	6.2	11.1	4.4	7.7	13.9
Water (Nyssa aquatica)	1.4	2.5	4.2	3.4	6.1	10.0	4.2	7.6	12.
Walnut, black (Juglans nigra)	1.8	2.6	4.3	4.4	6.2	10.2	5.5	7.8	12.8
Willow:									
Black (Salix nigra)	.9	2.7	4.8	2.1	6.5	11.5	2.6	8.1	14.4
Pacific (Salix lasiandra)	1.0	3.0	4.6	2.3	7.2	11.0	2.9	9.0	13.8
Yellow-poplar (Liriodendron tulipifera)	1.3	2.4	4.1	3.2	5.7	9.8	4.0	7.1	12.3

[1] Shrinkage values have been taken as one-third the shrinkage to the oven-dry condition as given in the last three columns of this table.

[2] Shrinkage values have been taken as four-fifths of the shrinkage to the oven-dry condition as given in the last three columns of this table.

springwood and summerwood. Since the denser summerwood shrinks more than the lighter springwood in both the radial and the tangential direction, the radial shrinkage of the ring is the weighted average of the radial shrinkage of both types of wood. The tangential shrinkage, however, is more nearly equal to the greater tangential shrinkage of the summerwood because the summerwood, which is denser and stronger than the springwood, causes the springwood to become compressed tangentially and to assume a dimension smaller than it would have if it were allowed to shrink independently. Pentoney (8) states that this theory proposed by Möreth largely explains the difference between tangential and radial shrinkage. Other explanations have been advanced, such as difference between the fibril angles in radial and tangential walls, differences in the thickness of the primary walls in the radial and tangential directions, and difference in the number of cross walls along the radial and tangential axes.

Although shrinkage is variable in normal wood, certain abnormal types of wood contribute to increased variability. Compression wood, which is common to softwoods, shrinks considerably more longitudinally but less transversely than normal wood. The strands of the fiber walls of compression wood make a large angle with the longitudinal axis of the fiber, rather than lying nearly parallel. Tension wood, which is found in hardwoods, also has excessive longitudinal shrinkage, although the reason has not been determined. Particularly lightweight wood of some species has a greater longitudinal shrinkage than heavier wood of the same species. This rule does not apply to light and heavy woods of different species. Cottonwood, a light wood, does not shrink appreciably more lengthwise than oak, a heavy wood.

The large void volume that wood contains is subject to change by drying stresses, or possibly by liquid tension. The drying stresses are affected by the manner in which the wood is dried. Wood dried in a dry kiln at relatively high temperatures generally shrinks more than wood seasoned in a yard at relatively low temperatures. When high relative humidity is combined with high temperature, shrinkage is greatest.

Because shrinkage is highly variable, the shrinkage of any individual piece of a certain species may vary considerably from the average for the species. The shrinkage values given in Table 1, therefore, are more applicable to large numbers of boards cut from a single species rather than to individual boards.

Effects of Shrinkage and Swelling

Shrinkage starts as soon as any drying takes place. When a tree is felled and cut into logs, the ends and places where the bark has been knocked off begin to dry. As the drying progresses, end and surface checks may develop from the tensile stresses set up, because the shrinkage of the drying surfaces is resisted by the main bulk of the log. If the whole log were to become dry, the end and surface checks would develop into wedge-shaped cracks pointing towards the center, or pith. These cracks would not be the result of drying stresses set up by moisture gradients, but the result of the inherent difference between the tangential and the radial shrinkage of the wood. The size of the cracks that would develop is related to the difference between the tangential and radial shrinkage values for the species. The width of a single crack, at its widest point, can be calculated by the following formula:

$$C_w = \frac{\pi d}{100} (T - R)$$

where

C_w = crack width in inches
d = diameter when green in inches, or in a rectangular timber, the distance from the faces to the pith
R = radial shrinkage in per cent
T = tangential shrinkage in per cent

Because of the difference between tangential and radial shrinkage, it is difficult to dry a form such as a transverse section of a tree trunk without cracking, because the wood must assume a deformation equivalent to the width of the crack.

When the log is sawed into lumber or other items and the seasoning process starts, shrinkage begins and continues until the seasoning is complete. The width, thickness, and length are reduced from what they were in the freshly sawed state. The reduction in length is generally so slight as to be unimportant. The reduction in thickness will determine the proper setting for sawing the rough lumber to dress

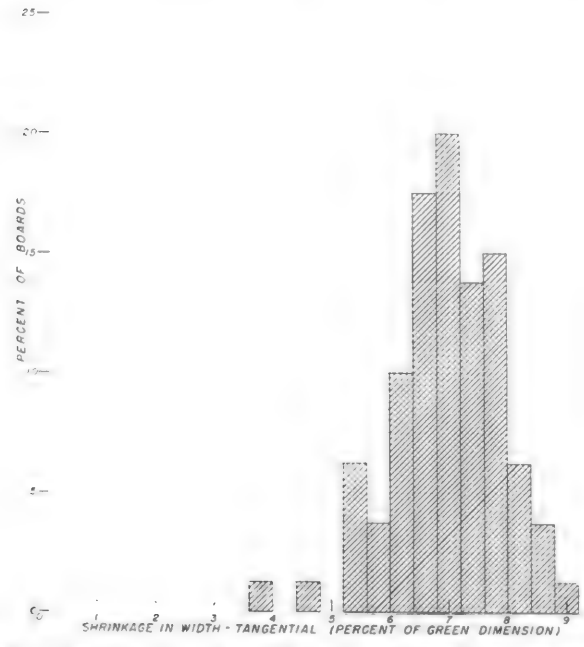

Fig. 2.—Frequency distribution of total tangential shrinkage values for plain sawed boards of longleaf pine heartwood.

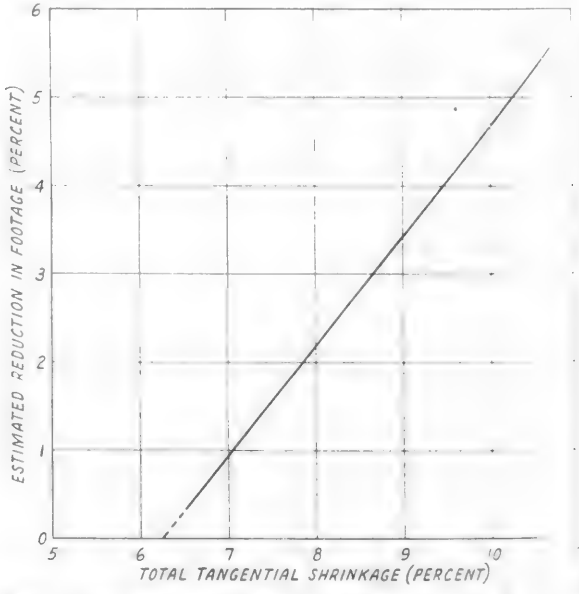

Fig. 4.—Estimated reduction in footage (per cent of air-dried tally) because of tangential shrinkage (per cent of dimension when green) for carload shipments of hardwoods when kiln dried to a moisture content of 5 per cent from an air-dried condition of 15 per cent.

to a certain finished thickness. Since quarter-sawed or edge-grained boards shrink more in thickness than plain- or flat-sawed boards, more allowance should be made for their shrinkage. The decrease in width is important with respect to the loss of footage based on the lumber scale.

Fig. 4 may be used for estimating the loss of footage. The chart is drawn on the basis of a 13 per cent moisture loss. The losses in footage may be prorated for different moisture losses. Under the conditions illustrated by this chart, lumber cut from a species whose total tangential shrinkage is not over 6 per cent should suffer no appreciable loss in footage. Edge-grained or quarter-sawed boards generally will not lose footage. Lumber shipments composed of wide boards will show a greater reduction in footage than shipments made up of narrow boards.

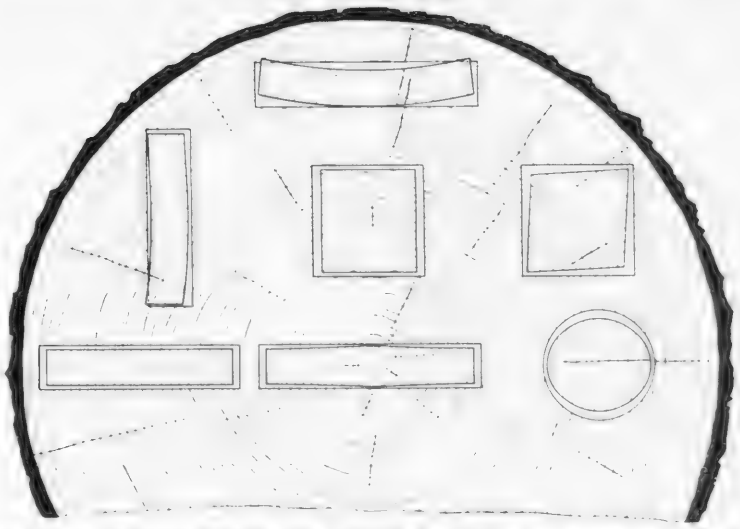

Fig. 5.—Characteristic shrinkage and distortion of flats, squares, and rounds as affected by the direction of the annual rings. The dimensional changes shown are somewhat exaggerated. Tangential shrinkage is about twice as great as radial shrinkage.

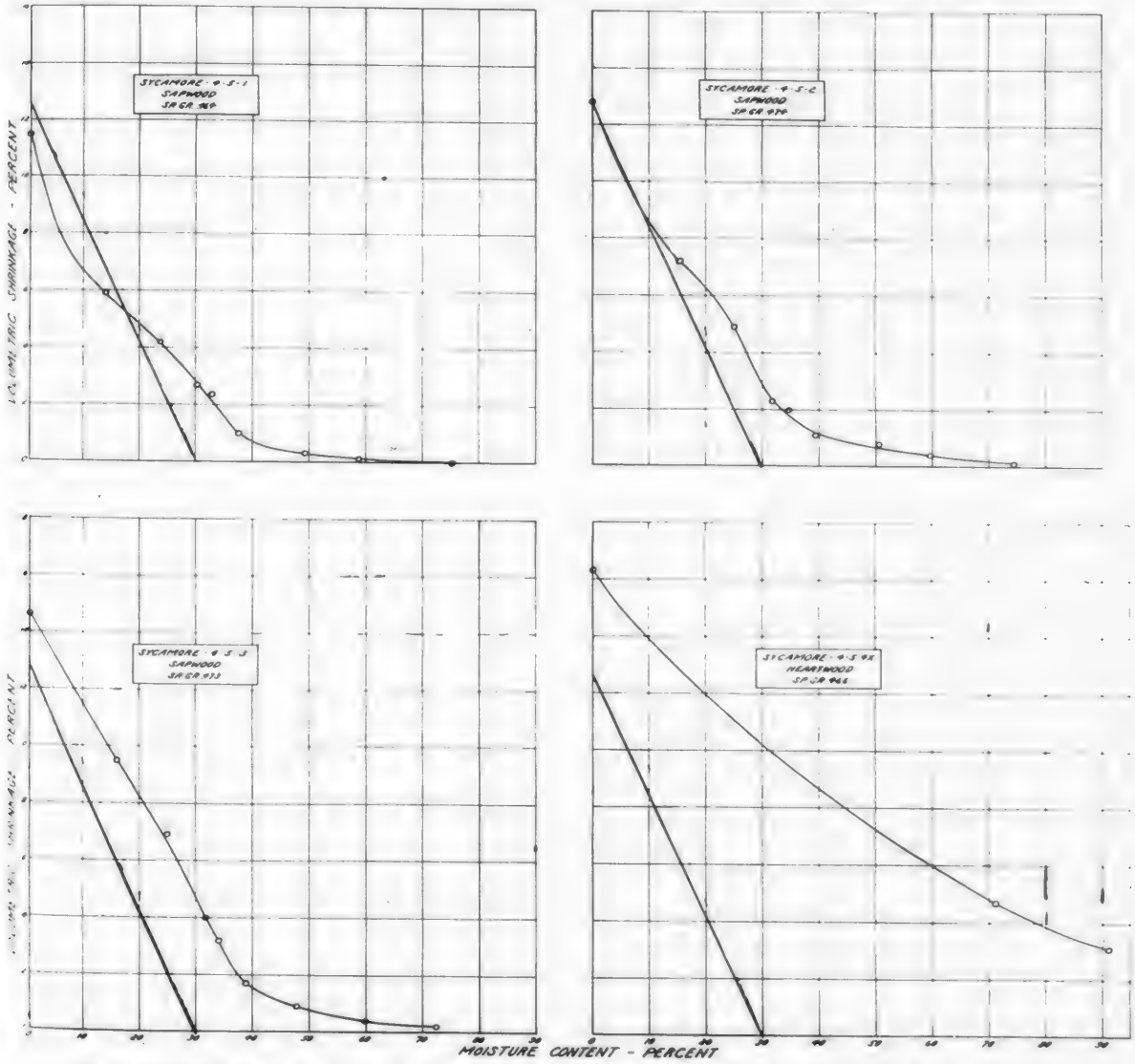

Fig. 3.—Volumetric shrinkage curves for four pieces of sycamore cut from the same radial board. The straight lines represent the calculated shrinkage, based on 30 per cent of water by weight, but 27 per cent by volume. The curved lines represent the actual shrinkage.

Shrinkage during seasoning not only causes a decrease in dimension but also causes changes in cross section and warping. Fig. 5 shows reductions in dimension and changes in cross section for various items with the annual growth rings in different positions with respect to the faces. The changes in the shape of the cross sections are caused by the difference between the tangential and radial shrinkage. Changes in cross section are also caused by set, which is the result of drying stresses. Set may cause a dry board to be thicker at the edges than in the middle, and all faces of a square to be concave.

Warp, which may be divided into cup, bow, crook, and twist, is caused by the difference in shrinkage in the three directions—tangential, radial, and longitudinal. Cup is common in flat-grained or plain-sawed boards, and all such boards would cup if permitted to dry and shrink without restraint. In a plain-sawed board, the position of the annual growth rings with respect to the two faces of the board is not the same. The result is that the outer face has a greater shrinkage potential than the face nearer the pith. Consequently, when the board dries and shrinks, the outer face tends to become concave while the opposite face tends to become convex. The tendency to cup varies inversely with the diameter of the annual rings contained in the board.

The other forms of warp, bow, crook, and twist, may be caused by spiral or diagonal grain, by localized distortions of grain, or by the presence of bands of abnormal wood. Where the wood fibers do not lie parallel or nearly parallel with the faces and edges of a board, a component of transverse shrinkage is developed that acts along the length of the board. The amount and character of warp depends on the position of the zones or areas of cross grain.

Bow, crook, or twist may also be caused by the presence of bands of wood, such as compression wood, that have abnormal longitudinal shrinkage. Wood near the pith often has abnormal longitudinal shrinkage, which is a good reason for "boxing the heart" so that the pith does not fall on one edge or face. Frequently, the wood in the outer portions of mature trees is lighter in weight than that nearer the pith. It will shrink more along the grain, and consequently may cause boards containing both types of wood to warp when they are seasoned.

Shrinkage during drying causes stresses that cause end, surface, and honeycomb checking. A check is a separation of the wood fibers that extends both radially and longitudinally. End checks appear as radiating lines. A honeycomb check is a separation of the fibers similar to an end or a surface check, but it occurs in the interior. It may or may not be a surface or end check that has closed on the surface. All checks are the result of tensile failures perpendicular to the grain. Checks generally originate at a point of weakness in the wood structure, either within the rays or at the junction of the wood-ray cells with the main body of cells, or in a resin duct. Once a check has started, it becomes longer and deeper as drying progresses.

Shakes are not generally classed as a drying defect. Failures within the springwood portion of the annual ring, or at the junction of the springwood and summerwood, are sometimes caused by drying stresses. The primary cause of such failures is radial shrinkage. This type of failure is most common in softwoods, and principally where there is a strong contrast between springwood and summerwood. Where shakes are present in the green board, they may increase in length when the board is dried. Ring shakes are often present on the ends of logs. If they are not trimmed from the board ends, they lengthen along the board when it dries.

Shrinking and the plasticity of wood are responsible for casehardening. Casehardening is a stressed condition of wood at a low and uniform moisture content throughout its thickness. The surfaces are in compression while the interior is in tension. During the early stages of drying, the surfaces are in tension and the interior is in compression. The surfaces become stretched, in a relative sense, and the wet interior becomes compressed. The dry surfaces become set or fixed, but the compressed interior, which is still wet, retains its ability to shrink. Because of these phenomena, a piece of wood that is completely and uniformly dry may contain considerable stress. The dry wood has lost most of its plasticity and gained in elasticity, so the stresses are within the proportional or elastic limits.

Casehardening can be relieved, because deformed or set wood retains its ability to shrink or swell. The surface zones that are in compression can absorb moisture. With absorption, the plasticity of the wood is restored and a swelling force is generated. The surfaces that were already in compression are subjected to additional compressive stresses. Since the surfaces are now wet and relatively plastic, they are compressed. When they are redried, their dimensions are reduced by the amount that they were compressed. Coincident with this action, the tensile force in the interior is increased and the interior zone may be stretched. The combination of the yielding of the surfaces and the interior eliminates or reduces the stresses and thus relieves casehardening.

Knots, unless they are intergrown with the wood around them, generally loosen during seasoning. A hole drilled in a green board will become smaller laterally as the board dries, but will retain its original dimension longitudinally. The wood that surrounds a knot, however, does not resemble the wood surrounding a drilled hole. The wood fibers surrounding a knot are distorted so that the wood tends to pull away from the knot in the longitudinal direction as it dries and shrinks, but tends to tighten against the knot in the lateral direction. The knot itself shrinks with loss of moisture, thereby contributing to its loosening in the longitudinal direction of the board.

The shrinkage of softwood knots is complicated by the compression wood in the bottom portion. Compression wood shrinks more longitudinally but less laterally than normal wood. Consequently, the knot does not shrink so much laterally, or in diameter, as the wood surrounding it. This helps to keep the knot tight in the lateral direction of the board. The knot does not shrink as much lengthwise as the board shrinks in thickness, however, and it projects above the surfaces of the seasoned boards.

Intergrown knots cannot loosen, because the wood fibers of the knot are continuous with those of the board, although they are turned at a sharp angle. Intergrown knots are likely to check when they dry. The checks radiate from the pith of the knot like heart checks around the central pith of the tree. Also, knots often have bark or pitch, which becomes hard and brittle, between them and the wood of the board. Because of these factors, knots are likely to be knocked out by machining or rough handling.

One of the prime objects in seasoning is to preshrink the lumber. No matter how thoroughly lumber is seasoned, however, some shrinking and swelling in service is inevitable because wood is seldom used under constant atmospheric conditions. Since wood is hygroscopic and responds to changes in relative humidity, its moisture content is constantly changing. Wood in service generally reaches an average moisture content, and changes in relative humidity cause fluctuations about this average. The damage resulting from shrinking and swelling of wood depends on the magnitude of the change in moisture content, the shrinkage coefficients of the species,

the character of the use, and the exactness of the requirements.

Large structural timbers are generally installed in a green or partially seasoned condition. The shrinkage that takes place when a large timber reaches an equilibrium moisture content is not usually important unless it causes checking and splitting, and subsequent loosening of fastenings. The shrinkage of inadequately seasoned lighter structural members, such as house framing, is highly important. Many houses are constructed so that the shrinkage of the framing members, particularly the joists, causes the central parts of the building to drop with reference to the outer walls. This may cause plaster cracks in interior partitions, distorted door openings in cross walls, and floors that are not level. Seasonal changes in atmospheric conditions within the building may cause shrinking and swelling that will result in a vertical movement of as much as ½ inch at the attic floor level of a two-story house.

The shrinking and swelling of ties, piles, poles, and posts, which are rarely thoroughly seasoned, are generally unimportant unless large cracks or checks occur. If checks or cracks occur after preservative treatment, untreated wood may be exposed, and decay may result. Alternate shrinking and swelling cause checks and cracks to increase in size, and fastenings may then become loose.

The shrinking and swelling of low-grade lumber for rough usage is not highly important, because the conditions under which the lumber is used are not likely to bring the lumber to a low moisture content. However, such lumber should not be used green, but should be air dry. Green lumber may shrink and loosen fastenings and joints. Where wooden containers are stored in heated or dehydrated storage, the moisture content of the lumber should be below that ordinarily attained in air drying.

With furniture, interior finish, flooring, musical instruments, sash and doors, caskets, and so forth, shrinking and swelling in use are highly objectionable because of the exacting use requirements. Shrinkage of parts of furniture may cause warping, opening of joints, and checks and cracks in the finish and in the wood. Highly polished surfaces of large areas may develop depressions and ridges that are conspicuous when viewed in proper light. Shrinking of doors, paneling, or interior finish may expose unfinished wood, while shrinking and swelling may open mitered joints.

Cracks in floors are caused by shrinking and swelling. Swelling causes the flooring to be compressed if the flooring continues to absorb moisture after the cracks have become closed, and when the floor redries, the cracks will be wider than before. Dirt and grit that accumulate in the cracks increase the amount of compression. Swelling also causes floors to bulge and may displace walls and partitions. Shrinking and swelling may loosen nails and cause the floors to squeak.

The sounding boards and backs of instruments like pianos and violins often split or crack, as do the wooden parts of wind instruments.

The strength of joints is seriously affected by the shrinking and swelling of the wooden members. A glued end-to-side joint is stressed when the components shrink or swell because the grain of the two pieces is not aligned and consequently the pieces attempt to shrink or swell by different amounts in the plane of the glue line. Side-to-side glued joints may be stressed when the pieces are of different species, when the grain of the pieces does not match, or when the pieces differ in moisture content at the time of gluing.

Wood-to-metal joints, where a piece of wood is surrounded by metal or where a piece of metal is surrounded by wood, may either loosen or tighten with shrinking or swelling of the wood. A wood handle set into a metal head, such as an ax or hammer, tightens with swelling and loosens with shrinking, while the reverse is true with a metal spike or peg set into a drilled hole in a piece of wood. A driven nail or spike, where the fibers are cut across their length and turned down alongside the nail or spike, loosens with shrinkage on the two sides in contact with the turned fibers, but tightens with respect to the other two sides. A nail or spike driven into end-grain wood becomes tighter as the piece of wood shrinks. No wood-to-metal joints are permanently tight, because when the wood tightens against the metal it may be compressed and become set. When the opposite phase of shrinking or swelling takes place, the joint becomes loose.

A somewhat different type of metal-to-wood joint is represented by a board fastened down by nails. If the board is dry when fastened down, an absorption of moisture will cause the wood of the board to swell against the underside of the nailhead. If the nail holds in the underlying member, the wood of the board may be compressed against the nailhead. If the nail does not hold, it is pulled to a slight extent. This process, combined with the loosening effect of the normal wood-to-metal joint between the nail and the board, contributes to a general loosening and pulling of the nail. Warping also helps loosen the nail. This loosening is all too common, because subflooring often becomes wet during the construction of a building, and it dries and shrinks after the dry finish floor is laid.

In cross-banded construction, where the grain of some parts is usually perpendicular to the grain of others, such as plywood and panels consisting of a core, crossbands, and faces, the components are so placed that they restrict the shrinking and swelling of each other. In plywood, each veneer restrains the shrinking and swelling of adjacent veneers, and its shrinking and swelling are, in turn, restrained by the adjacent veneers. The shrinking and swelling in the two lateral directions are greatly reduced, compared to solid wood, because wood does not shrink or swell much along the grain. A panel of solid lateral-grained pieces with cross-cleats or border strips on the ends resembles plywood in that the grain of some members is perpendicular to the grain of others. Changes in moisture content cause stresses that result in warping unless the construction is finely balanced.

Shrinkage of wood in service is seldom advantageous, but swelling may be. Certain types of structures, such as boats, tanks, or containers, utilize the swelling of wood to obtain tight joints. Once a boat or tank is tightened by swelling, however, drying will cause the seams to open, although the parts may be no drier than they were at the time of assembly. This is because the planks or staves have been compressed to some extent during the swelling process.

The shrinking and swelling properties of wood are used, to a limited extent, in control apparatus. Since wood is hygroscopic, it responds to atmospheric vapor and can be used to control relative humidity. As the relative humidity becomes lower than the setting, the wood element loses moisture to the air, and the resultant shrinkage activates a mechanism to supply moisture to the air. When the relative humidity is raised, the wood element absorbs moisture and swells, thus shutting off the moisture-supply mechanism.

Minimizing the Effects of Shrinking and Swelling of Wood in Service

The first step in minimizing the effect of shrinking and swelling is to reduce the amount of shrinking and swelling of the wood in service. Although the natural shrinkage of wood can be reduced by certain treatments, these treatments are not practical for wide application. Since a certain amount of shrinkage must be accepted, the wood should be preshrunk before it is put into use. This is accomplished by drying the lumber to a moisture content close to the midpoint of the range between the high and low ex-

Table 2.—ESTIMATED AVERAGE MOISTURE CONTENT OF THE PRINCIPAL INTERIOR WOODWORK IN 13 WIDELY SEPARATED CITIES DURING JANUARY AND JULY

City	Moisture content of interior woodwork		City	Moisture content of interior woodwork	
	July Per cent	January Per cent		July Per cent	January Per cent
Atlanta, Ga.	11.5	8.5	New York, N. Y.	12.5	7.0
Albuquerque, N. Mex.	6.0	7.0	Portland, Oreg.	9.5	9.0
Boston, Mass.	13.0	7.0	Salt Lake City, Utah	4.0	7.0
Dallas, Tex.	9.0	9.0	San Francisco, Calif.	10.5	10.5
Duluth, Minn.	10.5	5.0	Seattle, Wash.	11.0	8.5
Madison, Wis.	10.0	6.0	Washington, D. C.	11.0	8.0
New Orleans, La.	13.5	12.5			

Table 3.—RECOMMENDED MOISTURE CONTENT VALUES FOR VARIOUS WOOD ITEMS AT TIME OF INSTALLATION

Use of lumber	Moisture content (percentage of weight of ovendry wood) for—					
	Dry southwestern states		Damp southern coastal States		Remainder of the United States	
	Average* Per cent	Individual pieces Per cent	Average* Per cent	Individual pieces Per cent	Average* Per cent	Individual pieces Per cent
Interior finish woodwork and softwood flooring	6	4– 9	11	8–13	8	5–10
Hardwood flooring	6	5– 8	10	9–12	7	6– 9
Siding, exterior trim, sheathing, and framing†	9	7–12	12	9–14	12	9–14

*In general, the moisture content averages have less significance than the range in moisture content permitted in individual pieces. If the moisture content values of all the pieces in a lot fall within the prescribed range, the entire lot will be satisfactory as to moisture content, no matter what its average moisture content may be.

†Framing lumber of higher moisture content is commonly used in ordinary construction because material of the moisture content specified may not be available except on special order.

tremes attained in service. In this manner, the shrinking and swelling will be limited to that brought about by changes in moisture content above and below the midpoint. Since slight swelling is generally less objectionable than slight shrinking, the ideal moisture content at the time of installation is slightly below the midpoint of the expected moisture-content range.

The moisture-content range of wood in service depends on the exposure conditions. Temperature, relative humidity, and wetting affect the moisture-content, and relative humidity is normally the most important of the three. Table 2 gives the results of a study of the moisture content of woodwork within houses (7). The data in Table 2 provide a basis for the recommended moisture content values for house construction items (Table 3).

Although it is not always known beforehand where a product is to be used, a moisture content of about 8 per cent is suitable for interior uses in most regions of the United States. Lumber for the manufacture of products that have exacting use requirements should be kiln-dried to a moisture content of 5 to 8 per cent. Lumber that is thoroughly air seasoned to a moisture content of 12 to 15 per cent is suitable for rough construction and noncritical use. House framing members, such as joists and studs, and subflooring and sheathing are generally air seasoned. Such items, however, will lose moisture when the house is heated, and the resultant shrinkage may cause difficulties.

In addition to proper seasoning, shrinking and swelling difficulties can be minimized by the selection of species that have a low coefficient of shrinkage. Also, quartersawed boards shrink less in width than plain-sawed boards. Therefore, a floor made from quartersawed or edge-grain material develops narrower cracks than one made from plain-sawed material.

Shrinking and swelling difficulties may be minimized by proper construction features. Plywood panels represent the ultimate in the reduction of shrinkage or swelling in the lateral directions, but not in thickness, where they shrink and swell somewhat more than solid wood. The lateral shrinkage and swelling is nearly equal in the two directions with respect to the grain of the face plies. However, the shrinkage or swelling in length along the grain of the face ply is greater than along the length of a solid board of normal wood. Boats planked with plywood sometimes develop bulges or hollows between the frames, because the plywood swells somewhat in the lengthwise direction, where strip planking laid fore and aft remains smooth.

The furniture panel, with its core, crossbands, and face veneers, represents a member in which lateral shrinking and swelling are reduced greatly, although not quite so much as in plywood. Where pieces of wood are assembled in such a way that the grain directions of some are at right angles to each other, the connections should be made to accommodate shrinking and swelling wherever possible. Cleats should be fastened by screws in slots, rather than in tight holes, or by clips inserted into grooves. The ability of the fastenings to permit some slippage, while still holding firmly, will relieve stresses that would otherwise cause warping.

Wood is exposed to fluctuating conditions, and protective coatings and finishes of good moisture resistance reduce the range in moisture content through which the wood goes. The shorter the duration of the damp and dry periods the more effective are the coatings. During a continuous exposure to constant conditions, all protective coatings lose their effectiveness. When coatings or finishes are used, as on a table top for example, both the top and bottom should receive the same protection. If this is not done, a difference in the rate of moisture loss or pickup between the two faces may cause warping. The end-grain surfaces of items such as doors, should receive a protective coating, even though they are invisible. Likewise, interior finish and trim should be back-painted to retard changes in moisture content with changing conditions.

Wood exposed to rain and sunshine or occasional immersion in water should be protected from weathering by coatings of paint. The paint protects the surface of the wood from rapid wetting and drying. Rapid wetting and drying in succession, with the accompanying swelling and shrinking, tend to cause many minute surface checks to form, which contribute greatly to the process called weathering.

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Dimensional Stabilization of Wood: Part II. Crotonylation and Crotylation[1]

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By crotonylation of pyridine-swollen wood with crotonic acid and acetic anhydride, antishrink efficiencies from 49 to 73 per cent were attained. It is believed that by this treatment the wood was mainly acetylated. Upon soaking, some of the introduced acyl groups were leached. Crotylation of pyridine-swollen wood with crotyl chloride gave antishrink efficiences up to 80 per cent, but the wood was heavily degraded.

Crotonylation

Theoretical and Historical

MIXED ESTERS OF CELLULOSE may be formed by the reaction of acetic anhydride and the anhydride of a higher fatty acid upon cellulose in the presence of a suitable catalyst. Clarke and Malm (1) have shown that acyl groups from propionic or butyric acid may be introduced into a cellulose ester without employing the anhydride if these acids are present in an esterification mixture in which some other active anhydride is present. Butyric acid in this way may be used in conjunction with acetic anhydride or a mixture of acetic anhydride and acetic acid to give a mixed ester of cellulose. The ratio of butyric acid to acetic acid in the product will be proportional to the concentration of the corresponding acyl groups in the esterification mixture.

Although crotonic acid in the anhydride form may be made to react with cellulose to give cellulose tricrotonate, vigorous catalytic agents in large quantities are needed to obtain satisfactory esterification products (2). Such products are easily hydrolyzed by mixtures of acetic acid, alcohol, and water.

Mixed esters of crotonic and acetic acids may be more readily obtained than the ester of crotonic acid alone. These materials may be prepared in a manner similar to the mixed esters of butyric and acetic acids above, but since crotonic acid is much less reactive than butyric, it is introduced to a lower degree than butyric acid under the same set of reaction conditions. A reaction mixture of such proportion to give 40 to 45 per cent butyryl from butyric anhydride and acetic acid, when employed with crotonic anhydride results in only 15 to 18 per cent crotonyl in the cellulose ester.

Cellulose crotonates are stable under ordinary conditions, undergoing no changes in composition or physical properties at room temperature. Under the influence of ultraviolet light, or at high temperatures, these esters become insoluble products. Although cellulose tricrotonate is most sensitive (forming an insoluble product after 24 hours at 100° C.), cellulose acetate crotonates containing less than 10 per cent crotonyl may undergo similar transformations.

Table 1.—ACYL CONTENTS AND ANTISHRINK EFFICIENCIES (A.E.) OF ACETYLATED-CROTONYLATED BALSAM FIR WAFERS UPON FIRST AND SECOND SOAK-TESTINGS

FIRST SOAK		SECOND SOAK	
Acyl Content, %	A.E., %	Acyl Content, %	A.E., %
13.9	63.1	12.7	57.1
15.0	49.7	12.2	61.7
15.6	60.3	14.7	61.5
16.0	53.9	13.8	60.7
16.2	73.4	15.0	63.8
17.0	66.5	15.6	65.1
18.2	67.6	15.9	66.1
18.2	51.2	9.9	52.1
20.9	58.5	11.8	55.4

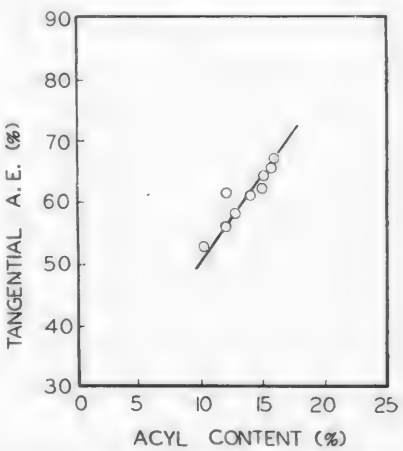

Fig. 1.—Relation between acyl content and tangential antishrink efficiency (A. E.) of crotonylated balsam fir upon the second soaking.

Experimental

Balsam fir wafers were swollen in pyridine and then placed in a solution of acetic anhydride (66 g.) and crotonic acid (50 g.) in pyridine (66 g.). The mixture was warmed to 60° C. for several days. The samples were dried at 110° C. for 72 hours. The long drying period was also designed to polymerize the crotonic acid ester. Soak testings were of 8-hour duration, swelling equilibrium having been attained after this time.

Results and Discussion

The crotonylated samples had ester contents from 13.9 to 20.9 per cent, and had antishrink efficiencies (A.E.'s) from 49.7 to 73.4 per cent. Upon soaking however, some of the introduced substance was leached. A second soak-test was made, the A.E.'s of the samples being shown in Table 1. The relationship between the acyl content and A.E. upon the second soaking results from Fig. 1.

This shows that the relationship is similar to the relationship between the acyl content and A.E. for samples which were acetylated only. It is believed that by this treatment the wood

[1] This paper constitutes part of a thesis submitted by D. F. Arseneau in partial fulfillment of the requirements for the degree of D.Sc. in Chemistry, Graduate School, Laval University, May 1955. Financial assistance was given to M. Arseneau by the Shell Oil Co. and the Quebec Scientific Research Bureau.

[2] This paper was prepared while Dr. Arseneau was a graduate student at Laval. He is now on the staff of the Dept. of Chemistry, Xavier College, Sydney, N. S. Canada.

was mainly acetylated, that the amount of crotonic acid ester, if formed at all, was very small. Indications were that the crotonic acid was deposited within the wood and that, on soak testing, this substance was leached.

Crotylation

Etherification using the unsaturated crotyl chloride with pyridine as catalyst, was also attempted.

It was believed that this alkyl chloride would form a crotyl ether with the lignocellulose of wood. By polymerizing the unsaturated linkages of the ether, a three-dimensional polymer could eventually be formed. Such a treatment would impart great stability to the dimensions of wood.

Oven-dry balsam fir wafers were soaked in pyridine for 18 hours. They were then placed in a crotyl chloride solution in pyridine. The mixture was heated at 50° C. for four hours and then at 75° C. The samples underwent this treatment for between two and sixteen hours (at 75° C.). They were then dried at 95° C. for two days, thereby effecting polymerization. The samples were cooled, weighed, measured, and soak-tested for antishrink efficiency.

Although the treated wood exhibited a high degree of dimensional stability (as high as 80 per cent), it was so badly degraded, possibly by the action of eliminated hydrochloric acid or more likely by the crotyl chloride itself, that no further work was done on this treatment.

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Neutral Sulfite Semichemical Pulping of Alder

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Trends in semichemical pulping of hardwoods are discussed. An extensive research program was carried out to investigate the feasibility of pulping alder by the neutral sulfite semichemical process. A description is given of a commercial installation for manufacture of corrugating medium from alder.

Background

IT IS GENERALLY KNOWN that Weyerhaeuser Timber Company is now utilizing red alder. This wood is not only being pulped, but also a limited amount of lumber is being manufactured. Weyerhaeuser Timber Company has long been a believer in a program of complete utilization of its forests, and thus the utilization of alder is just another step in this direction.

Hardwoods have been pulped commercially for some time in other parts of the country, and in recent years hardwoods have been pulped by the neutral sulfite semichemical (NSSC) cooking process to produce a very good grade of corrugating medium. Since all of the NSSC corrugating medium used on the Pacific Coast was shipped in from Eastern mills, there seemed to be a need for a mill in the West.

However, before a commercial installation was made, an extensive research program was carried out to investigate the feasibility of pulping alder by the NSSC process. These pulping studies showed that alder could be pulped by the NSSC process and that a good corrugating medium could be produced. These studies led to the construction of a 200-ton NSSC pulp and paper mill at Longview, Washington.

Longview was selected as the site because of its central location with respect to the company tree farms, and also because the Longview kraft liquor system was large enough to absorb the NSSC spent liquor. In addition, the old calcium base sulfite acid plant was easily converted to a NSSC liquor making plant. The NSSC pulp and paper mill went into production in April 1955.

There may be a question as to what the neutral sulfite semichemical pulping process is. Actually, the name is just what it says—neutral sulfite—which means that the cooking operation is carried out using a neutral solution of sodium sulfite plus a little sodium carbonate buffer. The semichemical part of the name means that pulping is not completely effected by cooking the wood with chemicals but instead the final fiberizing is carried out by mechanical means. Thus, the chips are softened by cooking in a neutral chemical solution and final pulping is effected by fiberizing with a refiner.

This process was selected because it produces a pulp from hardwoods which makes an excellent corrugating medium. Pulp is produced in yields of 70 per cent or better as compared to 45 to 50 per cent for kraft or sulfite pulp. Therefore, the NSSC process produces not only an excellent corrugating medium, but also increases the yield from the wood which is in effect a more efficient utilization of the forests.

Historically, the idea of semichemical pulping dates back to 1874 when Mitscherlich (1)[2] treated wood with sulfurous acid and bisulfites under pressure and then fiberized the softened wood by rubbing or grinding. The use of neutral sulfites for cooking wood was proposed by Cross (2) in 1880.

The process used today is based on work done at the U. S. Forest Products Laboratory, which is described in a paper published in 1926 (3). This process involved three stages: 1. pressure impregnation; 2. a mild cook nearly neutral, using sodium sulfite and sodium carbonate or bicarbonate; 3. mechanical reduction of the softened chips. This is essentially the process we are using except that the pressure impregnation step is not used. The U. S. Forest Products Laboratory (4) has studied the NSSC pulping of red alder and reported on its use in making corrugating medium.

NSSC pulping might still be a laboratory curiosity if it had not been for the advent of the corrugated box. Originally, board made from straw was

[1] Presented at meeting of FPRS Pacific Northwest Section, May 7–8, 1956, in Eugene, Ore.

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[2] Numbers in parentheses refer to literature cited.

used for corrugating medium but this medium had a rather low crush resistance. Corrugating medium was next made by the kraft pulping process. This medium was an improvement over straw medium but it also lacked crush resistance. It was found that the crush resistance could be improved by using pulps with shorter fibers. Thus, hardwood was shown to make an excellent wood for corrugating medium when it was pulped by the NSSC process. The crush resistance is improved not only by the shorter fiber, but also by the amount of hemicellulose remaining in the pulp. Since hardwoods have more hemicellulose than the softwoods, they are more desirable for making corrugating medium. The NSSC pulping process also helps the natural advantage of hardwoods by removing only a small portion of the hemicelluloses.

With this background on why Weyerhaeuser is using alder and the NSSC pulping process, a description of their Longview operation follows.

Wood Preparation

Unpeeled wood is received by rail and by truck. The logs are 8 feet 4 inches in length, and the minimum and maximum diameters are 6 and 20 inches, respectively. We use about 60,000 cords of wood per year for the production of corrugating medium. After the wood is unloaded, it is either stored or used immediately.

The wood is barked by an Anderson barker. This barker was made in Sweden and removes the bark by mechanical action. The barker does a fairly good job and can operate at speeds up to 80 lineal feet per minute. After barking, the wood is chipped and stored in concrete chip silos. The chips are removed from the bottom of the silos by a shear plate and transported to the digesters by a rubber conveyor belt. The chips charged to the digesters are measured by a weightometer located over this conveyor belt.

Cooking Liquor

The liquor for cooking the chips is made by dissolving sodium carbonate, or soda ash as it is commonly called, in water and sulfiting it in a packed tower. The soda ash is received in powder form and by using suitable instrumentation is dissolved continuously to make up a 14 per cent solution. This solution is pumped to the sulfiting tanks.

The soda ash solution is sulfited by pumping this solution into the top of a tower packed with ceramic tile while sulfur dioxide is pumped into the bottom of the tower. The gas and liquid come into intimate contact and the soda ash reacts with the sulfur dioxide to form sodium sulfite. The soda ash sodium sulfite solution is circulated through the tower until nearly all the soda ash has been converted to sodium sulfite. The sulfur dioxide used in the sulfiting process is prepared by melting sulfur and then burning the molten sulfur with an excess of air.

After the liquor has been sulfited, it is pumped to the digester measuring tank and is ready to be charged to the digester. More sodium carbonate, or buffer, is added to the digester before the cook is started. The function of the buffer is believed to be that of neutralizing the wood acids, while the sodium sulfite is believed to react with lignin to form an insoluble lignosulfonic acid which soon reacts with sodium to form the soluble sodium lignosulfonate.

Cooking

The chips are cooked in 3600-cubic-foot vertical digesters. The chip charge is largely hardwood but a small quantity of softwood is also used. Actually, a 100 per cent hardwood pulp produces a better corrugating medium but it is difficult to run on the paper machine. The hardwood is essentially alder, but small amounts of cottonwood, maple, and ash are also used. The amount of sodium sulfite and sodium carbonate charged to the digester is 12 per cent and 3 per cent respectively, on an oven-dry wood basis. Spent liquor is also added so that the initial liquor to chip ratio is about 4.5 to 1 and the final ratio is about 5.5 to 1.

The digester is heated with direct steam and the cooking liquor is circulated through the digester during the cook. The chips are cooked for almost 3 hours and the maximum temperature reached during the cook is around 345° F. The digesters are blown into a typical kraft blow tank.

The partly fiberized chips are diluted with spent liquor and pumped to four Sprout Waldron disk-type refiners which are operated in parallel. The stock is metered to the refiners by a star valve and thickened by a rotary screen to a consistency of about 16 per cent. The fiberized stock is diluted with spent liquor to about 1 per cent and washed by an IMPCO two-stage, two-drum vacuum washer system. The pulp yield of washed stock is about 70 per cent.

The pulp leaves the washers at a consistency of about 13 per cent and is stored at this consistency until it is used by the paper machine. The high density storage is fitted with a dilution system in the bottom of the tank so that the pulp can be diluted to about 3 to 3½ per cent consistency before it is pumped to the paper mill storage tank.

The spent liquor recovered by the washers is used for dilution, washing, or is added to the kraft spent liquor, which is concentrated and burned. Thus, the used NSSC chemicals become a part of the kraft recovery system and reduce the amount of kraft makeup chemicals.

Paper Mill

The pulp from the paper mill storage tank, white water from the wire pit, and the broke from the paper machine are pumped to an Oliver vacuum saveall. The stock is then put through two Jones Double D disk refiners which operate in parallel, four jordans which operate in parallel, then through a battery of centricleaners and finally to the headbox of the machine. The paper machine is a Beloit fourdrinier machine which trims 146 inches.

The production of corrugating medium is about 200 tons per day. Board quality is controlled by testing the corrugating medium for basis weight, caliper, moisture, porosity, and Concora. The Concora test is run by corrugating a strip of medium and subjecting it to a crush test in a compression tester.

Conclusion

From the foregoing experience, it is concluded that alder, which was formerly regarded as a weed species, is now coming into its own as raw material for the manufacture of corrugating medium. This is only the beginning of alder utilization and the future may bring uses which are not even dreams today.

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Swelling of Paint Films in Water: XI. Mixed-Pigment Paints in Linseed Oil

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A study was made of the relation between swelling and composition systematically for all possible combinations of basic carbonate white lead (low swelling), zinc oxide (high swelling), and rutile titanium dioxide extended with magnesium silicate. In addition, there were studied a brief series of paints in which antimony oxide was substituted for white lead as the low-swelling pigment, and another in which paints of constant pigmentation were made with various proportions of unbodied and bodied linseed oil.

PREVIOUS PAPERS in this series have shown that, in films of linseed oil paints, some pigments bring about much greater swelling in water and other pigments less swelling than that of the unpigmented oil vehicle (5)[2]. It was found also that the swelling of paints made with mixtures of high- and low-swelling pigments is not an additive function of the pigment composition but is dominated by the high-swelling pigments (1, 2).

The purpose of the experiments reported in this paper was to study the relation between swelling and composition systematically for all possible combinations of basic carbonate white lead (low swelling), zinc oxide (high swelling), and rutile titanium dioxide extended with magnesium silicate. In addition, there were studied a brief series of paints in which antimony oxide was substituted for white lead as the low-swelling pigment, and another in which paints of constant pigmentation were made with various proportions of unbodied and bodied linseed oil.

The experimental procedures have been described previously (6). The symbols for expressing the pigment composition of paints also have been reported previously (1, 2) and are explained by footnotes in the tabulations of results.

A single lot of each of the pigments provided the material for all paints in this work. There were marked variations, therefore, in the viscosity of the experimental paints, but limitation of each pigment to a single lot avoided uncertainties from the minor variations in swelling power previously found among different lots or grades of a given kind of pigment (5).

Change in Zinc Oxide When Poorly Stored

The first effort to make the experimental paints disclosed a property of zinc oxide that may not be widely known. Those paints that contained zinc oxide were found too low in weight per gallon, and the discrepancy was proportional to the content of zinc oxide. Examination of the lot of American process zinc oxide chosen revealed that it had become carbonated to the extent of 48.3 per cent. When the history of the lot was traced, it was found to have been purchased a number of years earlier and to have been stored for much of the time in an unheated storage shed that was often sufficiently humid to corrode steel. A French process zinc acid stored in the shed was 64.5 per cent carbonated, although a portion of the same shipment that had been kept in a laboratory under dry conditions contained only 1.10 per cent of carbonate. Two other American process zinc oxides from the shed, though perhaps stored there for a shorter time, contained only 0.19 and 1.65 per cent carbonate, respectively. Correspondence with the maker of one of the pigments confirmed the facts that long storage without control of temperature and humidity may result in carbonation of zinv oxide, and that French process oxides are usually more sensitive to carbonation than American process oxides.

A second set of experimental paints was made in which the zinc oxide came from a lot found to contain only 0.26 per cent of zinc carbonate. Both sets of paints were tested for absorption of water and swelling. Paints made with the highly carbonated zinc oxide usually swelled slightly more than similar paints made with nearly pure zinc oxide, but the relation between swelling and pigment composition was essentially the same. Results are, therefore, reported only for the paints made with zinc oxide nearly free from carbonate.

Swelling of Films of TLZ Paints

Table 1 records in detail the absorption of water, swelling and related data for unweathered films that were 10 days old when the soaking tests began. The results with films that were weathered for 15 days in a weatherometer before testing them by soaking in water are reported in Table 2. Changes in density, losses of soluble matter while soaking, and shrinking when redried follow the patterns of behavior described in previous publications. This discussion may therefore be confined to the effects of paint composition on the absorption and swelling of the films.

The trends among paints made with white lead, zinc oxide, extended titanium dioxide, and their mixtures are more easily followed in the graphic presentation of Fig. 1 in which pigment composition is represented by position on a triangular surface. Pure white lead paint occupies the lower left-hand apex of the triangle, pure zinc oxide paint the lower right-hand apex, and lead- and zinc-free extended titanium dioxide paint the upper apex. Paints with mixtures of white lead and zinc oxide fall along the base of the triangle; those with mixtures of white lead and extended titanium dioxide along the left edge of the triangle; those with mixtures of zinc oxide and extended titanium dioxide along the right edge, and those with mixtures of all three kinds of pigment at points within the area of the triangle. The proportion by volume of any one kind of pigment in a mixture is represented by the distance of the point from the side opposite the apex designated for that pigment.

The center of each circle drawn on

[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2] Numbers in parentheses refer to Literature Cited.

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the triangle represents the pigment composition of one of the paints tested. The upper number within a circle is the percentage of volumetric swelling found for the corresponding paint film before it was weathered, and the lower number is the swelling found for the weathered film. For all unweathered films, the volumetric absorption of water was nearly the same as the volumetric swelling, because swelling efficiencies were between 99 and 103 per cent. Most weathered films had swelling efficiencies within the same limits. Exceptions were weathered films of paints L, Z, and $T_{14}L_{70}X_{16}$ with 56, 89, and 85 per cent swelling efficiency, respectively and paints $L_{75}Z_{25}$, $L_{50}Z_{50}$, and $T_{14}L_{40}X_{46}$, each with 96 per cent efficiency. Low swelling efficiency means that absorption exceeded swelling, presumably because the films became porous.

Fig. 1 shows that the extent of swelling of mixed-pigment paints was dominated by the high swelling of zinc oxide. Whereas films of pure white lead paint swelled 9.3 per cent before and 3.5 per cent after weathering, replacement of only one-fourth of the white lead by zinc oxide raised the swelling to 53.5 per cent before and 25.4 per cent after weathering. Similarly, films of extended titanium dioxide paint swelled 48.0 per cent before and 13.9 per cent after weathering but when only one-fifth of the pigment was replaced by zinc oxide the swelling rose to 80.3 per cent before and 51.5 per cent after weathering.

No such dominance was exhibited by extended titanium dioxide, which is a moderately high-swelling pigment. On the contrary, the swelling of films of the two lead-titanium paints along the left edge of the triangle was less than proportionality to the content of extended titanium pigment would indicate. Forty percent of white lead paint in $T_{14}L_{40}X_{46}$ sufficed to keep the film from swelling as much as unpigmented linseed oil before weathering and to keep the swelling far below that of unpigmented linseed oil after weathering. Films of raw linseed oil without pigment swell about 22.0 per cent before weathering and about 20.5 per cent after weathering (6). White lead, therefore, has a dominating effect in the direction of low swelling over such pigments as titanium dioxide and magnesium silicate.

Because zinc oxide stimulates swelling so powerfully, by far the greater

Table 1.—DATA FOR UNWEATHERED, FREE FILMS OF PAINTS OF VARYING COMPOSITION

Composition of films: Pigment at pigment volume 0.30	Linseed oil: Unbodied portion	Linseed oil: Bodied: Proportion	Linseed oil: Bodied: Viscosity[a]	Density of nonvolatile in liquid paint	Density of film: Dry	Density of film: Swollen in water	Density of film: Redried	Initial thickness of film	Absorption of water A/V_0	Swelling in volume ΔV_s	Swelling efficiency $\frac{(\Delta V_s)\ V_0}{A}$	Redried volume ΔV_r	Loss in weight soaking S_2/V_0
	Percent	Percent						Mils	Percent	Percent	Percent	Percent	Gm. per 100 cc.
TITANIUM-LEAD-ZINC PAINTS MADE WITH UNBODIED LINSEED OIL													
L_{100}	100	0	.....	2.70	2.87	2.74	2.91	4.6	**9.3**	9.3	100	-2.7	3.7
$L_{75}Z_{25}$	100	0	.....	2.60	2.80	2.19	2.85	4.5	53.5	53.5	100	-2.7	3.4
$L_{50}Z_{50}$	100	0	.....	2.53	2.70	2.02	2.74	4.2	68.1	68.0	100	-2.9	4.0
Z_{100}	100	0	.....	2.34	2.49	1.80	2.53	4.0	87.0	**86.5**	99	-3.6	5.8
$T_{14}L_{70}X_{16}$	100	0	.....	2.43	2.61	2.42	2.64	4.2	14.6	14.9	102	-2.6	3.9
$T_{14}L_{57}Z_{29}X_{16}$	100	0	.....	2.36	2.54	1.94	2.57	4.1	65.0	65.0	100	-2.9	3.9
$T_{14}L_{43}Z_{43}X_{16}$	100	0	.....	2.30	2.47	1.85	2.50	4.4	73.0	73.2	100	-2.9	4.0
$T_{10}L_{40}Z_{20}X_{30}$	100	0	.....	2.18	2.35	1.80	2.38	4.1	69.0	**69.4**	101	-3.0	4.1
$T_{10}L_{30}Z_{30}X_{30}$	100	0	.....	2.14	2.32	1.78	2.35	4.3	71.6	71.8	100	-3.0	4.1
$T_{10}L_{20}Z_{40}X_{30}$	100	0	.....	2.11	2.28	1.73	2.32	4.0	75.3	75.6	100	-3.9	5.5
$T_{14}L_{40}X_{46}$	100	0	.....	2.04	2.19	2.01	2.22	4.2	20.6	20.4	99	-3.6	4.8
$T_{14}L_{30}Z_{10}X_{46}$	100	0	.....	2.00	2.17	1.77	2.20	3.9	54.0	53.8	100	-3.4	4.6
$T_{14}L_{20}Z_{20}X_{46}$	100	0	.....	1.98	2.15	1.74	2.18	4.2	57.5	57.5	100	-3.4	4.6
$T_{14}L_{13}Z_{27}X_{46}$	100	0	.....	1.97	2.13	1.70	2.16	4.2	62.3	62.3	100	-3.5	5.0
$T_{14}L_{7}Z_{33}X_{46}$	100	0	.....	1.94	2.10	1.67	2.13	4.1	64.1	64.1	100	-3.5	5.3
$T_{14}Z_{40}X_{46}$	100	0	.....	1.90	2.04	1.59	2.06	4.2	76.4	76.1	100	-3.2	5.4
$T_{20}L_{10}Z_{10}X_{60}$	100	0	.....	1.78	1.93	1.56	1.95	4.4	65.4	**65.4**	100	-3.0	4.3
$T_{20}L_{7}Z_{13}X_{60}$	100	0	.....	1.76	1.92	1.54	1.94	4.3	68.5	68.6	100	-3.9	5.3
$T_{20}Z_{20}X_{60}$	100	0	.....	1.74	1.89	1.49	1.92	4.5	80.0	80.3	100	-4.2	5.8
$T_{24}X_{76}$	100	0	.....	1.61	1.75	1.51	1.77	4.1	47.5	48.0	101	-3.6	4.0
TITANIUM-ANTIMONY-ZINC PAINTS MADE WITH UNBODIED LINSEED OIL													
A_{100}	100	0	.....	2.38	2.45	2.40	2.51	4.3	6.6	6.9	103	-3.5	3.7
$A_{75}Z_{25}$	100	0	.....	2.37	2.44	1.79	2.47	4.2	85.0	84.8	100	-4.7	4.5
$T_{14}A_{30}Z_{10}X_{46}$	100	0	.....	1.91	2.02	1.60	2.05	4.3	72.7	72.9	100	-3.5	4.0
$T_{14}A_{13}Z_{27}X_{46}$	100	0	.....	1.91	2.02	1.61	2.05	4.2	69.3	69.3	100	-3.4	4.3
$T_{20}Z_{20}X_{60}$ PAINTS MADE WITH MIXTURES OF UNBODIED AND BODIED LINSEED OIL													
$T_{20}Z_{20}X_{60}$	0	100	U	1.76	1.83	1.60	1.86	4.2	40.5	40.9	101	-2.7	2.8
$T_{20}Z_{20}X_{60}$	50	50	U	1.76	1.85	1.54	1.87	4.5	57.5	57.6	100	-3.0	3.9
$T_{20}Z_{20}X_{60}$	75	25	U	1.75	1.86	1.54	1.88	4.3	61.9	62.0	100	-3.4	4.1
$T_{20}Z_{20}X_{60}$	100	0	.....	1.74	1.89	1.49	1.92	4.5	80.0	80.3	100	-4.2	5.8
$T_{20}Z_{20}X_{60}$	0	100	Z3	1.77	1.85	1.65	1.87	3.4	31.7	32.1	101	-1.8	1.7
$T_{20}Z_{20}X_{60}$	50	50	Z3	1.76	1.85	1.55	1.87	4.1	56.2	56.6	101	-3.0	3.4
$T_{20}Z_{20}X_{60}$	75	25	Z3	1.75	1.85	1.53	1.87	4.5	60.6	60.7	100	-3.0	3.9
$T_{20}Z_{20}X_{60}$	100	0	.....	1.74	1.89	1.49	1.92	4.5	80.0	80.3	100	-4.2	5.8

[a] Pigments are indicated by the following symbols: L, basic carbonate white lead; Z, zinc oxide; T, rutile titanium dioxide; A, antimony oxide and X, magnesium silicate. For all of the paints in which it was used, each of these pigments came from the same lot. Subscript numbers indicate the percent of the pigment in the total pigment by volume.

[b] Viscosity in Gardner-Holdt scale in which U indicates approximately 6.27 poises and Z3 approximately 46.3 poises.

part of the area of the triangle in Fig. 1 represents paints of high swelling. Only the narrow strip along the left side of the triangle from the L-apex to the point representing a mixture of 40 per cent white lead with 60 per cent extended titanium dioxide includes paints that swell less than unpigmented linseed oil.

History Concerning TLZ Paints

The diagram shows that the changes in prevailing composition of house paints during the past 50 years have been in the direction of increasing film swelling until recently. Half a century ago most houses, at least when they were new, were still being painted with pure white lead paint, but mixed-pigment paints containing white lead and zinc oxide gradually began to gain an increasing share of the market. The lead-zinc paints were either "100 per cent pure" paints that contained no extending pigments, represented by the left-hand half of the base of the triangle, or they were extended lead-zinc paints in which the extending pigments could not much exceed 20 per cent of the pigment by volume without undue impairment of opacity. The shift to zinc-containing paints was the first and relatively greatest step toward high film swelling. It was accompanied by marked increase in number of cases of blistering and other early failures in coating integrity attributed to the action of water on painted woodwork.

Titanium dioxide and zinc sulfide, when first used in house paints about 30 to 35 years ago, usually replaced part of the extending pigment in the extended lead-zinc paints of the time. But extended titanium dioxide or zinc sulfide could replace white lead and zinc oxide without loss or with improvement of opacity and with advantages in cost and in resistance to soiling, checking, and durability of coatings. Prevailing formulation of house paints therefore moved steadily upward through the triangular area of Fig. 1 along a narrowing strip directed toward and finally reaching roughly the pigment composition TZ_{20} (the intersection of the topmost horizontal dotted line with the right side of the triangle). The trend during this period was to still higher film swelling, although the further increase was not so great relatively as the initial step from pure white lead- to zinc-containing paints. During this time zinc sulfide gradually succumbed to the competition of titanium dioxide.

Up to 1943, the vehicle in most house paints was unbodied linseed or similar oil except perhaps for small admixtures of moderately bodied oil. Since 1943, there has been general use of larger proportions, up to half the

Table 2.—DATA FOR WEATHERED, FREE FILMS OF PAINTS OF VARYING COMPOSITION

Pigment[1] at pigment volume 0.30	Linseed oil: Unbodied proportion	Linseed oil: Bodied proportion	Linseed oil: Bodied viscosity[2]	Loss in weight while weathering: S_1/V_o	Density of film: Dry	Density of film: Swollen in water	Density of film: Redried	Initial thickness of weathered film	Absorption of water: A/V_o	Swelling in volume: ΔV_s	Swelling efficiency: $(\Delta V_s)V_o/A$	Redried volume: ΔV_r	Loss in weight
	Percent	Percent		Gm. per 100 cc.				Mils	Percent	Percent	Percent	Percent	Gm. per
TITANIUM-LEAD-ZINC PAINTS MADE WITH UNBODIED LINSEED OIL													
L_{100}	100	0		18.9	3.14	3.04	3.09	2.9	6.3	3.5	56	+0.9	
$L_{75}Z_{25}$	100	0		10.5	2.96	2.58	2.97	3.1	26.5	25.4	96	-1.0	2.4
$L_{50}Z_{50}$	100	0		11.9	2.90	2.59	2.90	3.0	21.4	20.5	96	-1.0	1.8
Z_{100}	100	0		14.2	2.68	2.42	2.66	3.1	20.8	18.6	89	-.1	1.
$T_6L_{74}X_{20}$	100	0		14.7	2.78	2.68	2.77	3.4	7.4	6.3	85	-.6	.9
$T_6L_{72}Z_{10}X_{12}$	100	0		9.9	2.68	2.33	2.69	3.2	27.6	27.0	98	-.9	1.
$T_6L_{56}Z_{38}X_{12}$	100	0		10.3	2.63	2.36	2.63	3.2	20.4	20.0	98	-.5	1.
$T_{10}L_{40}Z_{20}X_{30}$	100	0		10.4	2.50	2.20	2.49	3.2	26.2	25.3	97	-.4	1.
$T_{10}L_{30}Z_{30}X_{30}$	100	0		10.0	2.47	2.22	2.46	3.3	20.9	20.5	98	-.5	1.3
$T_{10}L_{20}Z_{40}X_{30}$	100	0		11.8	2.43	2.18	2.42	3.2	21.2	20.8	98	-.4	1.7
$T_{14}L_{40}X_{46}$	100	0		18.1	2.36	2.31	2.41	3.3	8.1	7.8	96	-.9	1.7
$T_{14}L_{30}Z_{10}X_{46}$	100	0		13.1	2.30	1.93	2.29	3.4	40.0	39.4	98	-.7	1.7
$T_{14}L_{27}Z_{13}X_{46}$	100	0		12.7	2.28	1.90	2.27	3.5	42.6	42.0	99	-.3	1.6
$T_{14}L_{20}Z_{20}X_{46}$	100	0		12.2	2.26	1.88	2.24	3.4	41.4	40.8	99	-.05	1.5
$T_{14}L_{13}Z_{27}X_{46}$	100	0		12.9	2.24	1.95	2.23	3.3	31.0	30.7	99	-.05	.8
$T_{14}L_{40}X_{46}$	100	0		13.9	2.19	1.79	2.18	3.1	50.5	49.9	99	-.05	1.1
$T_{20}L_{10}Z_{10}X_{60}$	100	0		14.5	2.05	1.78	2.06	3.4	37.8	37.3	99	-.4	1.7
$T_{20}L_{7}Z_{13}X_{60}$	100	0		13.5	2.05	1.74	2.04	3.4	42.7	42.6	100	-.9	.7
$T_{20}Z_{20}X_{60}$	100	0		12.6	2.01	1.67	2.02	3.3	51.5	51.5	100	-1.4	2.0
$T_{24}X_{76}$	100	0		33.8	1.99	1.87	2.00	2.9	13.5	13.9	103	-1.1	1.1
TITANIUM-ANTIMONY-ZINC PAINTS MADE WITH UNBODIED LINSEED OIL													
A_{100}	100	0		11.1	2.60	2.57	2.61	6.8	1.7	1.9	113	-.4	.5
$A_{75}Z_{25}$	100	0		10.9	2.66	2.44	2.67	3.5	16.2	15.9	98	-.9	1.7
$T_{14}A_{30}Z_{10}X_{46}$	100	0		11.5	2.21	2.06	2.21	3.4	14.3	14.0	98	-.7	.7
$T_{14}A_{13}Z_{27}X_{46}$	100	0		13.1	2.03	1.91	2.03	7.4	13.9	13.8	99	-.7	
$T_{20}Z_{20}X_{60}$ PAINTS MADE WITH MIXTURES OF UNBODIED AND BODIED LINSEED OIL													
$T_{20}Z_{20}X_{60}$	0	100	U	4.8	1.93	1.80	1.93	3.3	16.8	16.6	99	-.3	
$T_{20}Z_{20}X_{60}$	50	50	U	6.0	1.95	1.80	1.95	3.6	18.8	18.8	100	-.4	
$T_{20}Z_{20}X_{60}$	75	25	U	4.6	1.92	1.77	1.92	5.9	18.9	18.9	100	-.8	
$T_{20}Z_{20}X_{60}$	100	0		12.6	2.01	1.67	2.02	3.3	51.5	51.5	100	-1.4	2
$T_{20}Z_{20}X_{60}$	0	100	Z3	2.1	1.88	1.79	1.89	5.2	12.1	12.1	100	-.4	
$T_{20}Z_{20}X_{60}$	50	50	Z3	6.6	1.96	1.79	1.96	3.2	20.8	20.8	100	-.8	2
$T_{20}Z_{20}X_{60}$	75	25	Z3	7.2	1.96	1.79	1.97	3.5	21.1	21.3	101	-1.1	
$T_{20}Z_{20}X_{60}$	100	0		12.6	2.01	1.67	2.02	3.3	51.5	51.5	100	-1.4	

[1] Pigments are indicated by the following symbols: L, basic carbonate white lead; Z, zinc oxide; T, rutile titanium dioxide; A, antimony oxide; and X, magnesium silicate. For all of the paints in which it was used, each of these pigments came from the same lot. Subscript numbers indicate the percent of the pigment in the total pigment by volume.

[2] Viscosity in Gardner-Holdt scale in which U indicates approximately 6.27 poises and Z3 approximately 46.3 poises.

total oil, of highly bodied oil. Bodied oil decreases film swelling, as discussed further on, but not sufficiently to make zinc-containing paints out of the high-swelling class.

Although the use of new kinds of low-swelling paints during the past 10 years has been minor their use is increasing. All of them are made without zinc oxide, and for all of them good resistance to blistering is usually claimed. One kind, called titanized white lead paint, contains white lead and titanium dioxide, usually without extending pigment, approximately in the proportions $T_{24}L_{76}$, which should be similar in film swelling to experimental paint $T_6L_{76}X_{18}$ in Tables 1 and 2 and Fig. 1 (swelling of unweathered film 14.9 per cent).

A second kind of blister-resistant paint is lead- as well as zinc-free and contains extended titanium dioxide in a bodied vehicle of some kind, often an alkyd resin, such as the one reported in a previous paper of this series (6). With such pigmentation, unbodied linseed oil vehicle makes paint that wastes away on weathering too fast for satisfactory durability, as is indicated in Table 2 by the very high loss in weight while weathering recorded for paint $T_{24}X_{76}$. The previous experiments (6) indicate that similar pigmentation of an alkyd resin of customary kind makes paint that wastes away less than one-third as rapidly and makes films that swell between 17.2 and 40.0 per cent before weathering and between 3.1 and 12.2 per cent after weathering. The lower percentages are for straight titanium dioxide pigmentation and the higher ones for straight magnesium silicate pigmentation.

A third kind of blister-resistant paint, often called "breather-type," has been made with a bodied vehicle, extended titanium dioxide, with or without a relatively small admixture of white lead at a pigment volume so high that the paint dries without gloss. It was alleged that such paints are so porous that they prevent blistering by letting moisture vapor pass through their coatings unusually rapidly. Commercial "breather-type" paints tested at this Laboratory have not proved more permeable to water vapor than other oil paints, but they have proved moderately low in film swelling (10).

Interest in the low-swelling, blister-resistant paints seems to be increasing rapidly at the present time, particularly in those of the second kind. Other means of accomplishing low film swelling and high resistance to blistering that are less restrictive of formulation would be highly desirable.

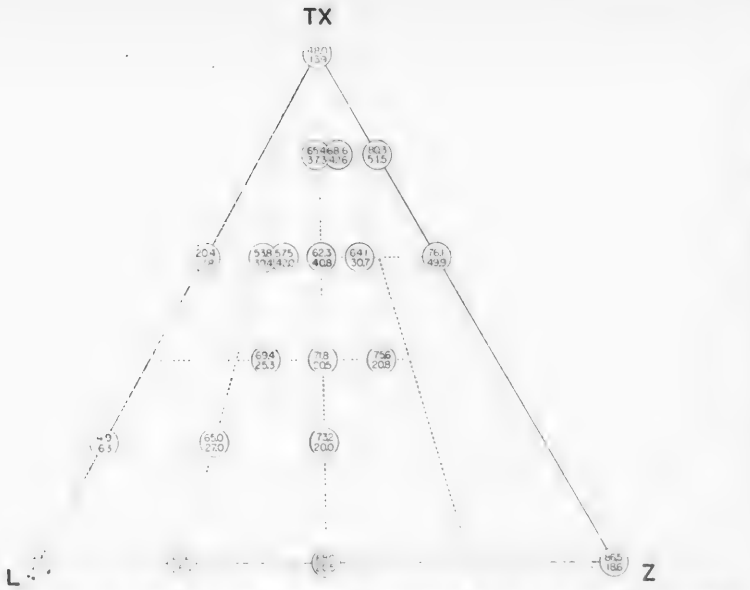

Fig. 1.—Swelling of films of linseed oil paints pigmented with white lead, L, zinc oxide, Z, titanium dioxide extended with magnesium silicate, TX, or their various mixtures at pigment volume 0.30. Each circle represents a paint that contained a proportion of each pigment represented by the distance from the center of the circle to the side of the triangle opposite the apex marked for that pigment. Within each circle, the upper number is the percentage of volumetric swelling of an unweathered film of the paint, and the lower number is the percentage of volumetric swelling of a weathered film of the paint.

Replacement of White Lead With Antimony Oxide

Since antimony oxide was found to make paint of even lower film swelling than white lead (5), it was of interest to learn whether antimony oxide is less seriously dominated by zinc oxide in mixed-pigment paints even though antimony oxide has gained little or no use in house paints in the United States. Tables 1 and 2 report four paints in which antimony oxide replaced white lead in corresponding paints of the TLZ series. The following pairs of paints should be compared: A_{100} with L_{100}, $A_{75}Z_{25}$ with $L_{75}Z_{25}$, $T_{14}A_{30}Z_{10}X_{46}$ with $T_{14}L_{30}Z_{10}X_{46}$, and $T_{14}A_{13}Z_{27}X_{46}$ with $T_{14}L_{13}Z_{27}X_{46}$.

When tested before weathering, the A_{100} film swelled less than the L_{100} film, but in all other pairs of paint films the one containing antimony oxide swelled more than the one containing white lead. Thus, zinc oxide's high swelling dominated over antimony oxide even more strongly than it did over white lead. When tested after weathering, however, the film containing antimony oxide always swelled much less than the corresponding film containing white lead. It is doubtful whether a gain in resistance to water after weathering compensates adequately for loss in resistance when the films are young. Abnormal moisture failures of house paints usually are most troublesome in the early part of paint life.

Effect of Admixture of Bodied Linseed Oil

Since house paints are made generally with mixtures of bodied and unbodied linseed oil and previous tests (6) showed that bodied oil paints are usually lower in film swelling than raw oil paints, it was of interest to learn how film swelling of a water-sensitive paint varies with the proportion of bodied and unbodied oil in the vehicle.

Paint $T_{20}Z_{20}X_{60}$ was selected for the water-sensitive pigmentation. Two bodied linseed oils were chosen, one of viscosity U (about 6.27 poises) and the other of viscosity Z3 (about 46.3 poises). With each bodied oil, a series of paints was made in which the oil vehicle contained 100, 50, 25, and 0 per cent bodied oil, respectively. Tables 1 and 2 report the results of soaking tests of unweathered and weathered films of the paints.

The unweathered film of paint made entirely with unbodied oil swelled 80.3 per cent. The film made entirely with bodied oil, U, swelled about half as much, 40.9 per cent, and that made entirely with bodied oil Z3, swelled 32.1 per cent. Unweathered films with the mixtures of bodied and unbodied oil swelled about as much as would be calculated from the weighted averages of the two constituents. Thus, mixtures of bodied and unbodied oil behaved additively with respect to swelling of unweathered films.

Weathering diminished the swell-

ing of films made wholly or partly with bodied oil to a considerably greater extent than it did that of unbodied oil films. Whereas the weathered film made wholly with unbodied oil still swelled 51.5 per cent, the film made wholly with bodied oil, U, swelled 16.6 per cent, those with mixtures of bodied oil, U, and unbodied oil swelled 18.8 and 18.9 per cent, that with bodied oil, Z3, swelled only 12.1 per cent, and those with mixtures of bodied oil, Z3, with unbodied oil swelled 20.8 and 21.3 per cent. Thus, for weathered films the bodied oils were dominant over unbodied oils in their mixtures.

Conclusions

1. The absorption of water and swelling of mixed-pigment paints made with linseed oil is strongly dominated by the high swelling of zinc oxide, even when this pigment is used in comparatively small proportions of the total pigment. All possible combinations of significant proportions of zinc oxide with titanium dioxide and magnesium silicate make films very high in swelling, which can be reduced somewhat by inclusion of white lead in the mixture but remains high even when there is a large proportion of white lead.

2. When zinc oxide is absent, the low swelling of white lead dominates the moderately high swelling of titanium dioxide and magnesium silicate. Mixtures with 40 per cent or more by volume of white lead with extended titanium dioxide may swell less than unpigmented linseed oil.

3. Antimony oxide, which swells less than white lead in single-pigment paints, fails to restrain the high swelling of mixtures that contain zinc oxide as much as white lead does when the films are tested before weathering, but it is more effective than white lead after the films have been weathered for some time.

4. Replacement of unbodied with bodied linseed oil in zinc-containing films reduces the swelling of unweathered films in proportion to the extent of replacement, but the swelling remains high even when all of the oil is bodied. After the films have been weathered for some time, however, films containing bodied oil become much more resistant to swelling and may reach fairly low swelling when no more than one-fourth of the oil vehicle is bodied oil. To attain fairly low swelling of weathered films, bodied oil or viscosity U may be as effective as bodied oil of considerably higher viscosity.

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BOOK REVIEW

Economic Geography of Industrial Materials Chapter 15: Forest Products

ROBERT S. MONAHAN

FORESTS PROVIDED the raw materials for the first export shipment of manufactured goods from the new world. Wood products were also largely responsible for the rapid development of the United States. Even though most of the original forests have been harvested, the author points out that this renewable resource is still of vital importance to industrial development.

A brief history of the development of each important forest region is very well presented. This includes information on the present forest area and its economic importance. Liberal use of tables clearly presents statistical data by states and regions making a convenient reference for both layman and technician. A footnote by the author referring to more recent statistical data emphasizes the point that the forests are a dynamic ever-changing resource subject to the whims of mankind.

Although foresters long ago realized the importance of man's influence on this resource, it was not until 1941 that the wood-using industry sponsored the American Tree Farm System to assure a continuing supply in the future. Tremendous progress has been made since then in re-establishing depleted forests as well as protecting them from fire and insects. The number of technically trained foresters employed by industry to manage this resource has increased six-fold since 1940. A challenge to these forest managers, however, is the fact that even though wood is being produced in sufficient quantity to meet demands, certain types of wood and high quality products, such as sawlogs, are being harvested faster than they are being grown.

Although lumber production has fluctuated with economic conditions, the present national output is still about the same as it was 25 years ago. New developments, such as the veneer industry, and rapid expansion of the pulp, paper, and allied industries have greatly increased the demand on the forests. This latter segment of the wood-using industry is now the fifth largest industry in the United States.

All branches of the forest products industry are directing considerable effort to obtain better utilization of the forest resources. This includes all phases from more and better growth on the forests, selection of logs for specific uses to mechanization and more complete utilization of each tree harvested. The author indicates research is essential to attaining complete utilization and that other countries are also very active in this respect. He states that 50 major countries and nearly 3,000 organizations are engaged in forest products research.

The author presents a fairly complete analysis of the resources available to the forest products industry, past history, and future trends, as well as selected references for those who desire to study the subject in more detail.

E. W. FOBES
U. S. Forest Products Laboratory

A Practical Approach to the Prevention of Decay and Termites in Building Construction

PANEL DISCUSSION

Reports results of a survey of 1200 homes built of untreated structural lumber and 759 homes with structural lumber which had adequate preservative treatment. Inspection of the untreated homes revealed that practically all suffered from serious deterioration caused by wood-destroying fungi and termites. Structural members in the treated homes were found to be as sound after 14 years' service as the day they were installed.

THE FOLLOWING DISCUSSION is the second part of a panel presentation by a building contractor, commercial termite control operator, an advocate of treated wood, and a representative of a treating company. The first part of the discussion was published in the June issue.

The discussion was presented at Session II, Wood Preservation, during the FPRS Tenth National Meeting, June 4–7, 1956, in Asheville, N. C. The session was conducted by the Wood Preservation Division under the chairmanship of Ira Hatfield, Wood Treating Chemicals Co., St. Louis, Mo. Dr. Ralph Lindgren, U. S. Forest Products Laboratory, Madison, Wis., was panel moderator and the discussion was recorded by Dr. J. B. Huffman, School of Forestry, University of Florida, Gainesville, Fla.

How to Prevent Decay and Termite Damage in Houses

C. MILES BURPEE

Director, American Wood Preservers Institute, Chicago, Ill.

Because the home building field is one in which pressure-treated wood is destined to play a more important role as the inherent advantages of treated lumber become more apparent to building officers, architects, builders and home owners, I should like to tell you briefly of a survey recently completed by the American Wood Preservers Institute.

Several months ago the AWPI was invited by the Building Research Advisory Board to participate in a study undertaken at the request of the Federal Housing Administration. The object of that study was to develop ways and means of building into new homes adequate protection against decay and termites.

For 34 years the AWPI, as a service organization, has cooperated with users of timber products to promote conservation and longer service life through pressure preservative treatment. During that entire period the Institute has been actively engaged in solving thousands of problems involving the depredations of wood-destroying rot and termites.

Because of the national importance of the BRAB project and the limited time at our disposal, it was impracticable for the Institute to make a thorough national survey. However, an intensive study was made of almost 2,000 representative homes within areas where they are subject to severe incidence of decay and termite attacks.

These surveys of existing conditions clearly show the grave problems that face a very large proportion of home owners and prospective owners throughout the country. Decay and termite damage present major challenges that must be faced and overcome.

Annual Loss $500 Million

Decay and insects in this country exact an annual toll of $500 million. Annual losses from the decay of untreated wood in service throughout the United States are estimated to be about $300 million, according to the U. S. Forest Products Laboratory. Another $150 million to $200 million comprises the annual loss caused by termites and other insects, according to estimates from the same source.

In the course of our survey AWPI engineers visited new and older housing developments. They interviewed and obtained the opinions of scores of building officials, architects, contractors, home owners, officials of lending agencies and many others associated with home building.

To observe building practices, AWPI engineers visited hundreds of homes during the course of their construction. Scores of modern homes were visited to observe the influence of landscaping and plantings after owners and their families had moved in.

For the purposes of our study and in order to provide authentic comparisons, the survey included the inspection of more than 1,200 houses built with untreated lumber and 759 houses in which pressure-treated structural lumber was used. Inspection of the untreated houses revealed that practically all suffered from serious deterioration caused by rot or wood-destroying fungi and termites.

Extensive Damage to Untreated Homes

Decay is much more general than termite damage, although termites present a more serious problem than decay in several areas. Acute structural damage was found in homes that have been built within the last three to 15 years and severe deterioration is not confined to older homes.

It is evident that homes "close-to-the-ground" have introduced even greater problems insofar as the use of untreated lumber is concerned. Many houses that were built to conform to designs and construction procedures which were considered adequate at the time of building have been severely damaged by decay and termites. In other instances faulty construction and improper ventilation have been contributing factors.

AWPI engineers have found that in many housing developments modern home planning makes it practically impossible to keep structural timber members more than a few inches away from the soil. Landscaping and upward grade revisions of surrounding soil after owners move into their new homes also tend to bring about closer proximity and contact of soil with wooden structural members.

These observations, by AWPI engineers, have been corroborated by records of local building maintenance officers, contractors, and pest control operators who are familiar with extensive and expensive repairs that have been made to overcome depredations in untreated structural lumber. The replacement of sills, joists and floors often involves major and costly renovation that extends far beyond the individual members themselves.

Building lumber today is cut almost entirely from fast growing species or stands. These woods usually contain a large proportion of sapwood which has relatively little resistance to wood-destroying fungi. However, when reinforced by adequate preservative treatment they are converted into excellent building lumber which is impervious to both decay and termites.

Adequately Treated Lumber Is Immune

That adequately treated wood is immune to such attacks has been proven by the inspection of 759 houses built with pressure-treated structural lumber in 11 different states and ranging from 2 to 41 years of age, and averaging 16.7 years. Pressure-treated structural lumber in these buildings was reported sound in every instance with one exception, where slight decay was found on a salts treated girder that had been exposed to leaching action directly under a leaking shower.

Untreated structural lumber adjacent to pressure-treated material in these homes generally was found to be in good condition. A few exceptions showed minor attacks. Termite activity in scrap lumber in crawl spaces was reported in several instances.

The value of pressure treated lumber for housing purposes is well exemplified in Charleston, S. C. During 1941 the City of Charleston Housing Authority built two wartime housing projects:

1. The George Legere Homes comprising 600 units of brick veneer with conventional untreated wood framing and sheathing were built on concrete slab floors.
2. The Ben Tillman Homes consisting of 400 units, of the crawl-space type, were built with pressure-treated sills, joists and girders.

Both of these properties were inspected by a representative of the AWPI in December 1955, approximately 14 years after they were built. These homes presented a very interesting contrast indeed. Decay and termites were prevalent in untreated homes and extensive damage was clearly evident. Officers of the City of Charleston Housing Authority estimated that fully 240, or 40 per cent of the units, already had received extensive repairs. These repairs included the replacement of untreated sills or plates, studs and practically all lumber items below the roof line. It was impossible to estimate the total damage to all units because so much of the decay and termite damage remains hidden until virtual collapse of the walls occurs.

Treated Homes in Excellent Condition

Outwardly, houses in both groups presented a neat, substantial appearance, but there the similarity ended. Contrary to widespread decay and termite damage in the George Legere Homes, those in the Ben Tillman tract are structurally sound because all joists and girders, as well as the frames of windows and doors, are of pressure-treated lumber. After 14 years of service, these members are just as sound as the day they were installed.

After the inspection of more than 40 individual houses, selected at random, by the AWPI representative, housing authority officials were interviewed individually. All agreed that no deterioration, by reason of decay and termites, had to their knowledge been experienced in any of the 400 units during their 14 years' service life with two minor exceptions which involved the replacement of a single board in each of two door frames, which had been damaged by termites.

How to Prevent Decay and Termite Damage

Although AWPI investigations have shown the importance of good design and good construction, the evidence of widespread damage by decay and termites clearly proves the inadequacy of these factors alone in modern housing. Complete protection, especially in areas of heavy incidence of decay and termite attacks, can be achieved only through the adequate preservative treatment of every structural member. However, AWPI surveys have shown that the possibility of attack by wood-destroying fungi and termites can be reduced to a satisfactory minimum by limiting adequate preservative treatment to structural lumber in the substructure and for such millwork as sash and doors.

Adequate preservative treatment for structural lumber should provide for the use of standard preservatives and their application by standard processes to assure the required penetration, distribution and retention in accordance with Federal Specification TT-W-571 and Standards C1 and C2 of the American Wood-Preservers' Association. Millwork such as window sash, window and door assemblies or other items should be treated in accordance with the standard requirements of the National Millwork Association.

Because it definitely has been shown that adequate control and consistent results in treating structural lumber can be attained only through standard pressure treatments as demonstrated in practice and by the latest report No. 2043 of the U. S. Forest Products Laboratory entitled "Study of the Preservative Treatment of Lumber," AWPI recommendations of pressure treatment for areas of heavy incidence, including the states of Florida, South Carolina, Alabama, Georgia, Mississippi, Louisiana, Texas (eastern) and California, are as follows:

Basement Houses:

1. Plates and sills on top of masonry foundations of outside walls.
2. Furring strips on masonry walls.
3. Frames of basement windows.
4. Outdoor steps, columns, exposed porch lumber and fences.

Crawl-Space Houses:

1. Plates and sills on top of masonry foundations. Where crawl space is less than 24 inches, girders, joists and subfloors also should be treated.
2. Frames for openings to crawl spaces.
3. Exposed steps, columns, porch lumber and fences.

Slab-on-Ground Houses:

1. Sills, plates and sleepers or nailers in contact with the concrete slab or masonry.
2. All studding resting on sills or plates in contact with the concrete.
3. Exposed steps, columns, porch lumber and fences.

A Look at Costs

Although first costs are important, nevertheless the minimum recommended use of pressure-treated structural lumber provides relatively inexpensive and excellent insurance against much more costly repair jobs. Pressure-treated sills, blocks, posts, girders, joists and subfloor will add only about $118 to the cost of a typical 30-ft. by 40-ft. home in a typical community, with prices based on purchase from a retail lumber yard.

The consideration of costs, however, should go beyond the first cost of the material and include also a comparison of annual costs over the service life of the building. Properly treated lumber, properly applied, will result in lower annual costs and yield a substantial return on the investment by reason of its much longer service life.

For instance, homes built under the Los Angeles city ordinance requiring the use of pressure-treated lumber and in effect from 1934 to 1949 are a good illustration of the effectiveness of the preventive value of pressure-treated lumber. According to the Bureau of Labor Statistics, 200,185 single family units were built in Los Angeles during those years. These were of the

cr[illegible]l-space type with clearance of less th[illegible] 24 in. and contain approximately 1,[illegible] f.b.m. of pressure-treated lumbe[illegible] comprising joists and all wood m[illegible]bers below the joists. The added co[illegible] per unit was approximately $30. C[illegible]rary to general belief, this added co[illegible] did not retard the building of h[illegible]es. Records of the Bureau of L[illegible]r Statistics corroborate this state[illegible].

comprehensive investigation made in[illegible]955 shows that less than 1 per cent o[illegible]he houses built under provisions o[illegible]he Los Angeles ordinance have been attacked by subterranean termites or decay. However, decay damage to untreated wood floors under shower baths of some of these houses resulted in repairs averaging approximately $150 per unit. On the other hand, homes built during the same period with untreated lumber outside the city limits of Los Angeles have shown an average infestation of 78 per cent by subterranean termites and 30 per cent by decay, with average repair bills of more than $300. In addition, pest control work involving removal of debris, providing better clearances and ventilation and soil poisoning amounted to approximately $65 per house.

Economy through proper preservative treatment of a wide range of timber products has been demonstrated for many decades by public utilities and railways. Pressure-treated crossties alone save the railways $775,000 per day, according to estimates prepared by the Bureau of Railway Economics of the Association of American Railroads.

Similar economies also may be enjoyed by American home owners. The investment of the average owner in his home is as great, proportionately, as that of railways in many of their properties. Because adequate preservative treatment is a paying investment for the railways, it also can be a paying investment for home owners.

However, the average man in America today buys his home ready-made just as he does his automobile. True, he may have a selection of models, but usually he has nothing to say about materials or the type of construction. Buyers are influenced largely by outward appearances, by floor plans, and by built-in conveniences for housewives.

The hidden material values that may be built into a house to provide a better home seldom receive adequate consideration from the buyer, primarily because of his lack of technical building knowledge. His inexperience with structural deterioration often precludes any consideration of adequate built-in protection. Builders usually do not provide guarantees against premature structural deterioration in wood frame construction and little does the average buyer realize the possibility of expensive repairs that could be avoided by an initial modest expenditure for treated structural lumber.

Certainly, under the circumstances, it would be to the decided advantage of lending agencies to adopt conservative preventive measures not only as protection for their investment during the mortgage period but also as a protective service for home owners.

Home Owners Need Protection

AWPI surveys of 1,200 homes built of untreated structural lumber in many different communities during the last 15 years clearly have shown the need for basic control that will protect the investments of home owners against premature deterioration by rot and termites. The effectiveness of adequate preservative treatment of structural lumber also has been proven by AWPI's surveys of 759 other homes in 11 different states. These investigations have shown the following advantages of using pressure-treated structural lumber:

1. It is immune to wood-destroying fungi and termites.
2. It provides much longer service life, with a minimum of 35 years.
3. It eliminates expensive structural repairs. Today's cost of replacing a single 20-ft. sill approximates $100, whereas pressure-treated sills for an average house cost only $35 in place.
4. It acts as a deterrent to decay and underground termites. Results of inspections show that treated floor systems have eliminated attacks on untreated lumber above that area.
5. It provides a safety factor against poor building practices.
6. It provides protection against poor practices of landscaping and plantings adjacent to the home.

These are the basic reasons why the AWPI recommends the use of pressure-treated structural lumber as a definite means of protecting American home owners. Moreover, these advantages may be attained at a nominal increase in capital outlay that will result in many appreciable benefits at lower annual costs.

Discussion

Bob Dixon (Osmose Wood Preserving Co.): How did you arrive at the cost figure of $118 for using pressure-treated lumber in an average home? I ask this because Mr. Smith stated that the cost of soil poisoning at $0.10/sq. ft. or $120 for a 1200 sq. ft. house is but a small fraction of the cost of treated lumber.

Mr. Burpee: When costs for various treatments are compared it is important that the same bases be employed. In arriving at my cost I used an average figure of $40/M for pressure-treated lumber and assumed that only the most vulnerable parts of the house would be pressure-treated. Mr. Smith may have based his statement on the fact that a greater amount of treated wood would be used in the typical house.

Ira Hatfield (Wood Treating Chemicals Co.): In our presentations so far, we have heard from a building contractor, a commercial termite control operator, and an advocate of treated wood. They have pointed out some of the problems connected with the use or misuse of wood in preventing decay and termite attack in building construction. It was our plan to have a lumber trade representative and an architect on this panel, but these assignments did not materialize. I will not pose as an expert in either of these fields (although I qualify by the definition that an expert is a person away from home), but will try to make certain observations to stimulate discussion in these fields.

Our theme for this session deals with a practical approach to the prevention of decay and termites in the building construction field. As FPRS members interested in the utilization of wood, we can well ask ourselves if modern design and uses of lumber have brought on conditions which make the use of wood uneconomical or unsatisfactory, or if wood can still hold its claim as the most versatile and useful of the building materials.

I am not alone in my belief that wood can and should remain king of the building materials, but we will have to acknowledge its shortcomings, put into practice the knowledge we have as to how to circumvent these shortcomings, and then do a better educational job with all concerned so that wood can perform in a very satisfactory manner. Unless this is done, we will lose ground to competitive or replacement materials.

Since wood performed so valuably in times past, what has focused attention on the fact that wood will decay or that certain wood insects such as termites will attack it? Was wood of a generation ago immune to these troubles, or has our modern architecture or styling brought on hitherto unknown problems? Perhaps both questions can be answered in the affirmative with certain qualifications. It is well known that the virgin timber of a generation ago contained less sapwood and was generally of such growth characteristics that it was less susceptible to decay under the conditions of use in buildings as applied at that time. The second growth wood can serve well and very satisfactorily

indeed if used under proper design conditions or if treated if such is necessary.

This brings us to the next phase of our question which was—Has modern architecture or styling brought on hitherto unknown problems? I have heard some people proclaim that architects must have gone into a trance and dreamed up new ideas that have created new problems. Actually, I would say architects try to design for utility, economy, style, and effect. The barn far removed from the house was good enough in the horse and buggy days—then when the first motor cars came, the garage was built closer to the house. It soon was realized that there was no need to walk in the rain from the house to the garage, or need to carry groceries down a driveway. Hence the garage became part of the house—and usually saved one wall in the building costs. Thus economy and utility were combined in this feature. We could similarly trace the trend to the slab-type house with its economies too, and many other features of today's homes. Air conditioning, new types of heating, and other features were developed to increase comfort and utility in the home, but they often increased the chances for decay or termite attack as brought out by previous speakers.

I bring these points up to show that there was reason back of many of the modern changes in architectural style, and perhaps our knowledge of what could happen and of how to prevent degradation has not kept pace with the changes in style.

R. J. Kowal (Southeastern Forest Experiment Station): During the war I was in an advisory position in connection with defense housing and we found it very difficult to work with architects and contractors because they were so poorly informed on basic aspects of termite infestation. Of course, the entomologists themselves have been lax in selling of preventive measures. The problem was made no easier by the bad state of affairs that existed in the pest control field during the 1930's—and there are still a few fly-by-night operators—but due to the self-policing within their trade the pest control people are doing a valuable and serviceable job at the present time. The problems present a real challenge to the pest control operators.

Use of Pressure-Treated Lumber

M. P. BROWN

Taylor-Colquitt Co., Spartanburg, S.C.

Termites and fungus rot are destroying millions of dollars worth of homes each year. North Carolina alone reports nearly $5 million yearly damage to 1.25 million homes in the state.

New homes are most likely to be attacked, reports Roy M. Carter, Professor of Wood Technology, School of Forestry, N. C. State College. This is due to high sapwood content of today's lumber, lack of natural resins and tars, and improper and inadequate building practices.

This heavy loss of money and our natural resource can be prevented by proper pressure treatment of all wood used in contact with or within 18 inches of the ground. Subfloor lumber and all wood below it should be pressure-treated.

Lumber of lower grades can be specified and pressure-treating of the items requiring it would save owners many times its cost.

Labor costs are at an all-time high and replacements are expensive, so I urge you to specify pressure-treated lumber be used in new constructions, or in replacements of decayed timbers in your homes. It is available at many lumber yards and numerous wood preserving plants throughout the country.

Wood preservers have recognized the vast potential market and opportunity to contribute to the conservation of our forests, but proper distribution of treated wood has been a problem. This is rapidly being overcome due to the construction of more plants and interesting more dealers in carrying properly pressure-treated lumber in stock.

Discussion

P. B. Mayfield (Allied Chemical & Dye Corp.): We all realize that something must be done to see that wood is properly used in building construction. Education is probably the best answer. The question is, to whom should education be directed and where should it be presented?

Mr. Brown: My opinion is that homeowners, architects, and building contractors should be taught the facts.

J. B. Huffman (University of Florida): Since it is to the lumber and wood preserving industries' best interest, it is my feeling that the industries should support and help organize adult education short courses in cooperation with the general extension divisions in our various colleges and universities throughout the country. Furthermore, I feel that the industry could organize traveling teams to present well-prepared displays and talks to civic groups, classes in our colleges of architecture, to building contractors, and to local and national meetings of the architects and building trade associations. The industry must join forces to really convince and educate the consuming public concerning the truth about the use and preservative treatment of wood. After this is accomplished, there will be plenty of business for all individual companies. There are three steps to my suggested program: first, sell wood; second, sell properly treated wood, and third, sell your own "bread and butter" products.

R. M. Lindgren (U. S. Forest Products Lab): I think the homeowner should be better informed, possibly through a FHA booklet which would tell the homeowner what he should look for.

G. G. Garlick (Protection Products Manufacturing Co.): Mr. Brown mentioned that for years the problem of supplying treated lumber for home construction was a serious stumbling block to its use in that field, and everyone interested in the wood preservation field recognized this point. About 20 years ago some of the more progressive lumber companies and lumber suppliers took steps to try and serve this building market. They installed treating tanks and started soaking lumber in water repellent preservative solutions for use in the residential and commercial market.

As more people began to realize that dry lumber, i.e., lumber below 20 per cent moisture content, would not decay, they realized that the soak treatment using a water repellent preservative could give good protection against decay and stain organisms. These treatments broke up the natural affinity that wood has for water and kept the wood well below the fiber saturation point under practically all circumstances. Should the wood on rare occasions get above the fiber saturation point, the presence of the toxicants in the treatment would give protection, so that the lighter retentions obtained with soak treatments gave adequate protection for residential construction.

Today there are in the neighborhood of 500 such treating tanks in operation in the country, many of which have been treating for over 20 years. The field experience and record to date in home construction shows that these soak treatments, using a good water repellent preservative, can give adequate protection against decay and stain, as well as dry wood termites, Lyctus beetles and many other insects that attack wood. Where the subterranean termite is to be reckoned with, then the heavier treatments should be used or the lumber soaked long enough to get at least a 4 lb. retention. However, if adequate termite shields or ground treatment is used, or other means of protecting against subterranean termites, then the lighter retentions—as light as 1 lb. per cu. ft.—can give adequate protection against decay and stain for above ground

pl[illegible]ion, where the treatment is a wa[illegible] repellent preservative.

B. Clements (Florida Pest Control Operator): Education of the buying public appears to me to be the key to proper utilization of wood products in construction with a minimum hazard of decay and insect damage. They need to be told that wood products in contact with cement products will attract moisture from the air by condensation and subsequently invite decay and termite damage unless the wood has been pressure-treated to resist such deterioration. Under modern building procedures, it is practically impossible to eliminate this condensation moisture and if it cannot be eliminated by building practice, the resulting damage should certainly be controlled by proper pressure-treatment of the timbers involved.

It has been my experience that the great majority of the buying public considers construction using wood products is far more susceptible to decay and termite damage than the use of concrete floors, etc. This feeling is certainly not borne out by our experience as we find that nearly 50 per cent of houses we are called upon to treat for subterranean termites are of concrete block construction with cement floors. I believe that a series of articles released to the public press on this subject will do a great deal to explode the myth of the termite protection via the concrete floor and, if this myth can be exploded, the trend would be definitely back to wood. A great majority of those requesting concrete floors are doing so primarily for the supposed termite protection and would not have concrete floors if they felt that this protection was not forthcoming.

The Merits of Steaming Douglas-Fir Veneer Blocks[1]

C. W. LICKESS

Plywood Superintendent, Timber Products Co., Division of Cyprus Mines Corp., Medford, Ore.

Methods of heating peeler blocks are discussed and the advantages outlined. The most important advantages reported are: increased recovery of veneer, longer life for lathe knives, easier peeling from a mechanical standpoint, faster drying, improved gluing characteristics, smoother unsanded panels, and easier sanded faces for finished plywood panels.

HEATING OF PEELER BLOCKS dates back to the early days of peeling veneer from logs. Flitches of high grade timber for slicing are still heated for maximum recovery of quality veneer.

Before the advent of mechanical barkers, the bark was removed by hand. Steaming the blocks broke down the cambium layer and released the bark readily. Since bark is a good insulating material, now it is found advantageous to remove the bark before steaming the block in order to secure the maximum heat penetration.

The answer to the many problems encountered in peeling the type of logs being utilized today is the heating of the peeler blocks. The investment required is nominal and the cost reasonable considering the benefits derived.

The heating can be done by submerging the blocks in tanks of hot water or by steaming them in vats or closed tunnels. Blocks should not be subjected to temperatures above 210° F. Saturated steam, such as engine or veneer dryer exhaust, is ideal for this purpose. A 16- to 24-hour period is required for good heat penetration, depending on the size of the blocks and the temperatures available.

If the steaming is done in a closed tunnel, the capacity of the individual tunnel must be governed by the volume of footage consumed during a 3- to 4-hour peeling operation. Once the tunnel is opened, the blocks awaiting their turn at the peeler will cool to some extent; if allowed to cool longer than the 3- to 4-hour limit, all the benefits of heating are lost. The knots seem even harder and the wood fibres contract to their natural state.

Advantages

The greatest advantage of heating, from a veneer recovery standpoint, is in the actual peeling operation. The increased flexibility and softened tex-

[1] Presented at meeting of FPRS Pacific Northwest Section, Feb. 6–7, 1956, in Longview, Wash. The paper was presented by Fred Underwood, Timber Products Co.

The Author: C. W. Lickess has 28 years' experience in the veneer and plywood field, working with Western softwoods and imported hardwoods. He has constructed several plywood plants and has had 16 years' experience as timber and plant manager in pine and fir operations.

Fig. 1.—Removing bark prior to the steaming operation.

Fig. 2.—End view of the steam tunnels or vats, of concrete construction with stainless steel doors.

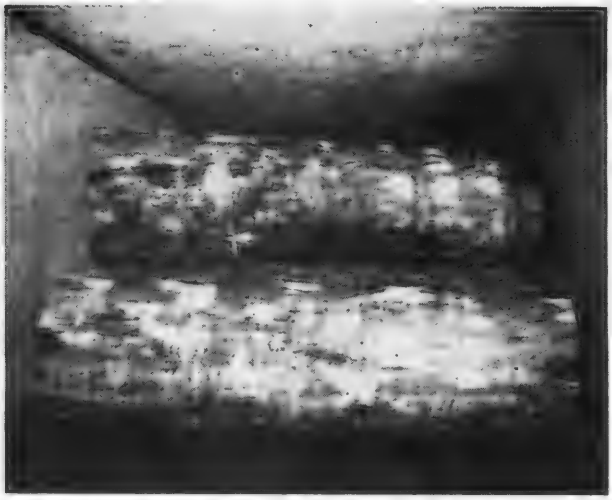


Fig. 3.—Blocks stacked in the vats by fork lift. Steam lines are at upper left and lower right.

Fig. 4.—Stack of dry veneer. Note the flatness and straightness.

ture of the heated wood fibres and knots will permit the use of a much keener cutting edge on the lathe knife and a lathe knife angle which will eliminate excessive "heel". The pressure, applied through the pressure bar to the block surface, is also cut down considerably. This all adds up to a lathe set-up requiring much less actual torque to accomplish the peeling process. Since this torque is applied to the block itself, through the lathe spindles, much less breakage is encountered, particularly in blocks having splits, partial pitch rings, or other mechanical defects. This set-up produces tight, smooth veneer which makes it unnecessary to allow extra thickness to compensate for rough peel.

It is the general practice with "cold peeling" to adjust pressure on the pressure bar between sap and heartwood but this is not necessary with heated blocks.

Hot peeled veneer will release a considerable amount of its moisture between the time of actual peeling and the time it reaches the green stack. The breakage in handling is reduced with hot peeled veneer due to "tight peel" and the relief of stresses produces sheet stock that lies flat on the loads.

In cold peeling the hard knots cause excessive nicking of the lathe knife, requiring frequent knife changes in order to maintain the quality of the veneer. In the hot peel operation, the knives may be run considerably longer. Also, the knives from the hot peel operation require much less grinding to restore the keen edge, which results in a substantial saving in grinding costs and knife replacement.

The texture of freshly peeled, hot veneer readily releases moisture through the open pores when subjected to high temperatures and low humidities in the drying process. Cold veneer, when subjected to these drying conditions, tends to collapse, causing "case hardening"; thereby sealing moisture within and retarding the natural drying process. The preheated and stress-relieved veneer accounts for a substantial reduction in the drying schedule.

It is common knowledge that stresses within a block cause warpage and breakage in the veneer when peeled cold and then subjected to severe drying conditions. Preheating the blocks at low temperatures and high humidities relieves these stresses before peeling, resulting in a dry veneer which lies flat with a minimum amount of checking and uneven shrinkage.

At the glue spreader a loose, rough peeled veneer will require considerably more glue through absorption and to cover the uneven surfaces of the veneer. A smooth, tight veneer can be run with a lighter spread and still assure a good transfer of glue. When under pressure in the press, the smooth veneer will give the even, uniform contact required for a good bond at less over-all pressure, which allows pressing the batch at a pressure well below the compression point of the wood. This eliminates the necessity of allowing extra thickness of the veneer at the lathe to compensate for any wood compression due to rough peel.

Almost all species of wood respond equally well to heating and can be hot peeled provided the summer growth of the wood is of sufficient density to support the spring growth during the actual cutting process. This applies to blocks containing pocket rot or white speck. As long as the wood fibres retain sufficient strength to hold the veneer together, these blocks can be hot peeled to advantage.

At the finished panel end of the production the smooth, tight quality of the hot peeled veneer faces make it possible to apply ordinary overlays directly to the unsanded panels without fear of a poor bond or rupturing due to rough panel surface. On sanded panels, these faces show a minimum amount of "hair check" or face checking which so often appears in cold peeled veneers. It follows, also, that the smooth faces sand much easier and more economically, as they do not require the heavy cutting necessary on rough stock.

In brief summary, the most important advantages of hot peeled veneer are: more veneer recovered from blocks peeled, longer life for lathe knives, easier peeling from a mechanical standpoint, faster drying of flatter laying stress-relieved veneer, improved gluing characteristics, smoother unsanded panels and for finished plywood, an easier sanded panel with higher quality faces.

Discussion

Q. How much are lathe checks diminished?

A. A comparison between hot and cold blocks shows that checks are appreciably diminished.

Q. Do you use a straight nose bar?

A. Yes.

Q. What is the result if the wood is decayed?

A. Some of it rubs off on the nose-bar.

Q. What is the time required for steaming?

A. Sixteen to 24 hours for logs up to 30 inches.

Q. What is the cost of steaming?

A. We have no estimate. Condensate is not collected but we use exhaust steam only.

Q. If condensate were returned would it be better to use live steam?

A. It may be better to use a steam-water mixture. Temperatures should not go above 210° F. or drying may result.

Q. Do you segregate large and small logs? Is it possible to oversteam?

Logs are often segregated for production reasons. It is not required but it is an advantage. It is possible to oversteam ponderosa pine which has high initial moisture content. A study has been made of the effect of steaming at 200°–210° F. Results are not yet available.

How are the tunnels loaded?

By lift truck.

What is the percentage saving in thickness?

We peel 1/10 at 0.004 in. over thickness, 1/8 at 0.004 in. over, and 3/16 at 0.0025 in. over.

Q. How are steam and water lines introduced into the tunnel?

A. Both lines feed into the exhaust line. Jets point downward on the top side and upward on the lower side.

Q. Do you allow for a temperature gradient into the log?

A. The inside temperatures are lower but this is usually core veneer where a smooth cut is less important.

Q. Do you use hot press or cold press?

A. We use a cold press at 165 psi on the panel.

Q. Diametric splits are common in heating hardwood logs. How about in fir and pine?

A. This is not a problem. Splits are confined to the core block. In peeling blocks with ring shake, the lower pressure required in heated blocks permits the knife to get closer to the ring before it breaks out. Recovery is thereby improved.

Q. Is condensation a problem with labor and equipment?

A. There are no problems with labor. Fog can create a problem with visibility and mold may develop inside the plant walls. Condensation has not bothered equipment. An adequate fan would help.

Q. Would a roller bar help peeling?

A. We have had no experience with one. The pressure bar works well.

Q. How often is the knife changed?

A. Normally every 8 hours. We can go 16 or even 24 hours, but 8 hours gives the best results. Too much heel on the knife makes for a rough peel.

Q. Is it any advantage to reheat the cores?

A. Normally it is not required. If 4-foot blocks are peeled on the re-run lathe (for 4 ft. x 4 ft. panels) the blocks are heated.

Q. What is the core diameter?

A. We use 8-inch chucks and have a core diameter of 12 inches. The re-run lathe uses 6-inch chucks. Average block diameter is 32 inches.

Q. What is the saving in drying time with heated blocks?

A. There is considerable drying of hot veneer before entering the dryer.

Q. Do you speed the drier or reduce the temperature?

A. We speed the drier.

Q. Are the standards of thickness easy to maintain?

A. It is not difficult to stay within the tolerance limits.

Grading of Green, Rotary Cut Douglas-Fir and Other Western Softwood Veneers[1]

O. J. BUGGE

Chief Engineer, Willard V. Young Co., Sumner, Wash.

The trend in the West Coast plywood industry to manufacture and marketing of green veneers is noted. This has brought a need for equitable veneer grade standards which will be universally acceptable. A set of general rules is presented for grading green veneer to make it qualify for plywood grade requirements in CS 45–55.

History

RIGID AND WELL-CONSIDERED panel specifications and grading rules have given Douglas-fir plywood an outstanding reputation for uniformity and guaranty of performance. However, since the plywood associations concentrate their attention on the assembly process as a means of control and on the finished product for acceptance, it is up to the manufacturer to establish sufficient control of the foregoing processes such as drying, green end, and log pond to avoid unnecessary degrading and development of rejects and subsequently, loss of material and efficiency.

In the past most plywood producers found peeler-logs readily available on the open market, or they were owners of timber and usually manufactured all green veneer needed in their plywood operation. A relatively new trend in the Pacific Coast plywood industry is the manufacture and marketing of green veneers. Plywood operators who have found it increasingly difficult to line up reliable and economic sources of peelable logs are encouraging this development. Separate "lay-up plants," which are finding less and less overflow material available

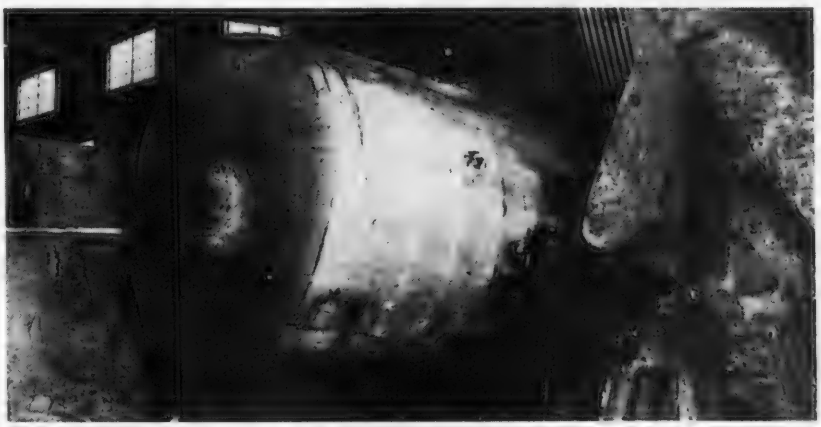


Fig. 1.—Before the blocks can be peeled, the bark is removed in a mechanical barker. Usually this is a scraper, rosser, compression, or combination-type machine.

[1] Presented at meetings of FPRS Pacific Northwest Section, February 6–7, 1956, in Longview, Wash., and Northern California Section, April 27, 1956, in San Francisco, Calif.

The Author: O. J. Bugge graduated as forest products engineer in Bavaria, Germany, was assistant engineer and later production manager for a Norwegian milling and wood manufacturing firm for four years. Since 1948 he has been active in the West Coast door and plywood industry as quality control and project engineer, plant superintendent, and in veneer selling and consulting before accepting his present position.

Fig. 2.—After barking, the peeler block goes to the lathe where it is unwound in a continuous strip. This is the process that produces the distinctive grain pattern of rotary cut veneer. As the veneer leaves the lathe, it is held temporarily in multi-decked storage trays 150 feet or longer.

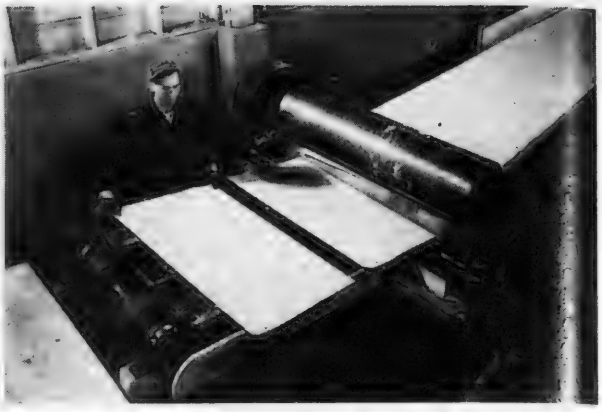


Fig. 3.—Four-foot veneer, for core, is clipped to 27-inch wid s on a rotary clipper and stacked up ready for drying.

from the full-time plywood operations, are depending almost exclusively on the green veneer producers for their existence.

Manufacturing Green Veneer

The various green veneer mills in operation may be divided into "four-foot" and "eight-foot" operations, from the standpoint of equipment facilities as well as from the type and grade of veneers produced.

The four-foot mill produces core and underlay veneer ranging in thickness from 1/10 to 1/5 inch and from 54 to 66 inches, measured parallel to the block-axis and clipped on a back-roll or selective clipper to a standard width of 27 inches, with random widths developing. This type of operation frequently relies on smaller, second-growth timber and on relogging of cut-over tracts for a raw material supply. At times four-foot plants are operated in conjunction with sawmills to better the log purchasing position, the material utilization, and to increase the sales return on a given raw material cost. Some four-foot mills concentrate on cull logs and the marketing of white speck material, commonly known as "bargain board," for low grade plywood and for decorative plywood products.

Four-foot mills with selective clippers are, as a rule, able to offer 4 x 4-foot veneers and 8 x 4-foot crossface material for hardwood underlay. However, since the grade expectations for such dimensions are usually higher than for regular core, it also depends on log types available.

The regular eight-foot green veneer operation with conventional 110 or 113-inch lathes, clippers, and tray system has rapidly grown in popularity on the Pacific Coast over the last five years. This type of veneer plant is usually considered the major operation in any mill set-up. The reasons are the initial capital investment necessary and operating cost, both of which are considerably higher than for a core-mill or four-foot operation. Furthermore, the greater operating capacity of an economically operated eight-foot green veneer mill requires a considerably larger log supply. On the other hand, many eight-foot veneer producers have found it advantageous to include a core lathe and/or a small sawmi in their operation for fuller utilizati of low grade and small diameter log nd for better log recovery.

Supplying Green Veneer

The grades generally offered b the eight-foot mills are:

A & Ap (atch): for face m rial only.

MR (Mill Run): log run v neer with an expected min. porti n of A & Ap, which is require for sanded and exterior plywood

CD: for sheathing and int rior, coldpressed plywood.

Bargain Board: white speck and oversized knots are permitted in this grade. Used for lowgrade and sometimes decorative plywood.

The plywood producers who purchase veneer from several sources have frequently found noticeable differences in the quality of similarly classified and priced material. Differences of this

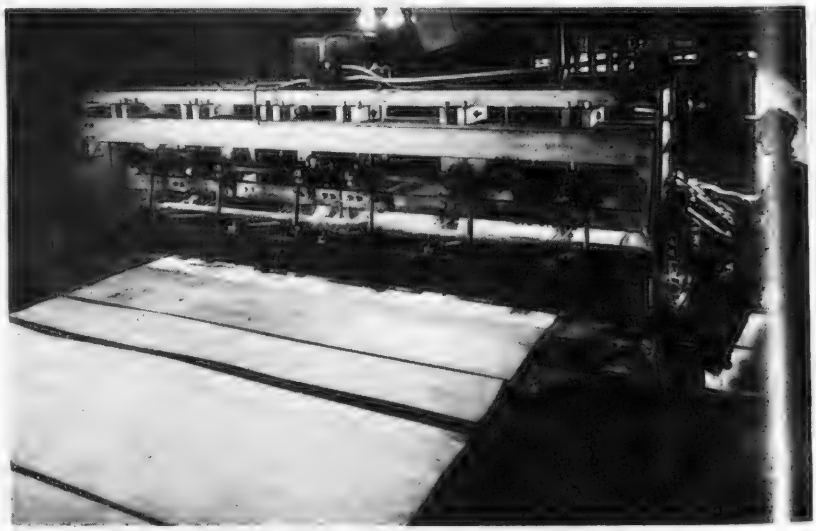


Fig. 4.—Highly skilled clipper man cuts out defective portions of veneer and ob ains the maximum number of full-size sheets of veneer possible within the limitations o the quality of the material.

cha: cter can have several reasons, such as rying growth characteristics in log: from different areas or altitudes, qua y of manufacture, based on the pee thick and thin occurrences, sheet-squ eness, etc. Not uncommon is the ven mill's misinterpretation of effec or results of certain veneer manufa uring characteristics, such as rough pee ruptured grain, checks and splits in rther processing in the plywood pla .

Quality Standards of Green Veneer

The rapid growth of the West Coast plywood industry has accentuated the already critical log situation and caused at least a momentary shortage of 8-foot veneer, with an understandable slackening of the veneer quality in general.

A receptive market and unusually attractive prices have resulted in many valuable but also some new inexperienced business enterprises. With log supplies being the limiting factor, the profit realization has in many cases not been comparable to what the mill operators estimated or sometimes were led to believe. In order to take up the slack and since there are no set grading rules for green softwood veneers, some producers may have attempted to sell their veneer for sanded and exterior plywood grade manufacture, when veneer for sheathing and interior grades was all that rightfully could be developed. Consequently, the plywood producers are frequently finding an overpercentage of random width and under-grade veneers which run their manufacturing cost up to unreasonable proportions or actually prevent them from manufacturing plywood of guaranteed quality standards.

Separation of the green end from the lay-up unit, both geographically and financially, will inevitably continue to pose a problem for the buyer, who is poorly served, and for the veneer producer, who does not have a realistice evaluation of his log sources, capital investment, or operating profits. Furthermore, misinformation and disdisagreement as to the veneer requirements are expensive to the plywood as well as the veneer producers, disadvantageous to the plywood buyers, and harmful to the industry as a whole, unless such happenings are curbed by some equitable veneer grade standards, developed on the basis of existing plywood grades and universally accepted by most reputable producers.

GRADING RULES FOR ROTARY CUT, GREEN DOUGLAS-FIR AND OTHER WESTERN SOFTWOOD VENEERS

When veneer is bought and shipped on the basis of "Mill Run", the following is understood: At least 30% to be A & Ap and random widths not to exceed ⅓ of the shipment.

Furthermore, the A portion is to be at least 50% of all A & Ap.

When veneer is bought and shipped on the basis of "Sheathing", the following is understood: At least 50% C and random widths not to exceed ⅓ of the shipment.

Defects	A Grade Soud Face	Ap Grade Patchable to A (Sound Face)	C Grade Int. Face. Ext. Core and Back	D Grade Int. Core and Back
Knots		Not over 1" largest dia. and not more than 3 such defects per 12" of width	Tight, sound, 1½" largest dia.	Allowed
Knotholes			Not over 1" largest dia. and not more than 5 per 12" in width	Not to exceed 2½" largest dia. Any number
Other Open Defects (Incl. Wormholes)	Not allowed			
Pitchpockets			Not over 1 x 2"	Not over 2 x 4"
Torn Grain		Not allowed	Not allowed	
Rough Grain and Lathe Checks			Slight	Slight
Rot or Decay			Not allowed	
Pitchstreaks	Not over ⅜" in width and half length of sheet, and only if blending with color	As for A Grade	Allowed in any amount	Allowed in any amount
Discoloration	Admitted	Admitted		
Cracks	Limited in number and not over 3 in 54" and 1 in 27" sheets	As for A Grade	Tapering to a point and not wider than ⅛" and not extending over 24" in length	As for C Grade
Splits	Only if tight and not over 12" in length in 54" and 27" sheets only	As for A Grade		
Smallest width of any random piece	10"	14"	8"	8"

Suggested Green Veneer Grades for Western Softwoods

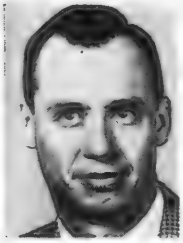
For the purpose of grading green veneer to make it qualify for plywood grade requirements in CS 45–55, a set of general rules is outlined here. These rules have been introduced to and are now used by several veneer producers.

When discussing these rules with Dr. H. O. Fleischer of U.S. Forest Products Laboratory, attention was called to other pertient factors such as, recent findings by the Laboratory concerning the relation of gluebond quality to the roughness on veneer. Glue joint tests made on Douglas-fir veneer bonded with a soybean no-clamp glue have indicated that a substantial reduction in joint strength may occur when the roughness depressions of the veneer surfaces were as deep as 35/1000 inch. Yet roughness depressions as great as 40/1000 inch are sometimes seen on commercially produced veneer.

Procedures for measuring roughness on rotary cut veneer are outlined in a report prepared by John F. Lutz of the Forest Products Laboratory. In a report by T. E. Batey, Jr. of D.F.P.A., the importance of proper cutting techniques is stressed and methods for measuring the extent of face checking in plywood are introduced. To establish the effect of non-uniform thickness in veneer, tests were conducted by the quality control division of the M & M Wood Working Co. in 1951. The writer, who was then in charge of this department, found that abrupt variation of thicknesses between the various pieces in a layer of cross-core exceeding 20/1000-inch would consistently cause unsatisfactory bond when using urea or phenolic resins, and sometimes blisters occurred in the latter case.

Although not entirely conclusive, these examples suggest that other requirements beyond mere physical grade specifications are necessary to render veneer consistently serviceable to the plywood industry.

Whether considering the grade specifications alone as the first step towards a workable green softwood veneer standard—or going all the way by specifying maximum tolerances for roughness, knife-checks and uniformity of thickness, a green softwood veneer standard would certainly mean rounding another milestone in our progressive veneer and plywood industry.



Finishing Wood Veneers and Pressboard to Close Tolerances with Coated Abrasives

HARVEY L. BENNETT
Products Engineer, Behr–Manning, Troy, New York

TOLERANCE, for as long as the word has existed, has been a term almost exclusively devoted to the metal finishing trade. However, there is evidence of an ever-increasing need for tolerance finishing in the woodworking industry, especially where thickness control is desired on pressboard and on wood veneers.

Pressboard, which is widely used to back up decorative plastics, must be of uniform thickness with a good bonding surface. Uniform thickness is a "must" when two pieces are butted together, as, for example, in continuous counter applications. The high gloss reflective surface of the plastic surface requires an absolutely level base without waves to look its best.

Wood veneers are finding widespread use today both in their original flat form and molded shapes. Before the finish is applied, a sanding is necessary to remove imperfections and to prepare the surface for proper finishing. Finishing with stroke sanders or pad sanders is expensive both from the standpoint of time and damaged stock.

Tolerances can be held to ±.002 on the Lightning Micro-Grinder, a machine designed and built by the Curtin–Hebert Co., Gloversville, N. Y. Originally this machine was developed to sand wide web sheets of leather, plastics, cork, rubber and metals to precision tolerances. Equally true tolerances can be held on wood and wood veneers. The Micro-Grinder produces this degree of accuracy through the use of coated abrasives, spirally wound on the cast iron grinding roll of the machine. The machine ranges in widths from 12 to 80 inches but widths of 40 to 52 inches are standard. Two benefits are derived from this method;

Pressboard: Precision tolerances can be achieved, and the resulting finish is ideal for glue adhesion. Depending on how much stock is to be removed, it is generally found that Durite, Garnet or Adalox paper, combination paper and cloth, or fibre in grits 36 and finer will do a satisfactory job.

Wood Veneers: Prefinishing and sizing of wood veneer can be quickly accomplished.

Fig. 1.—Feeding wood veneer through Curtin–Hebert's Lightning Micro-Grinder. Here, the operator is using 3/0 (grit 120E) Closekote Garnet paper to finish the surface of veneer prior to laying-up.

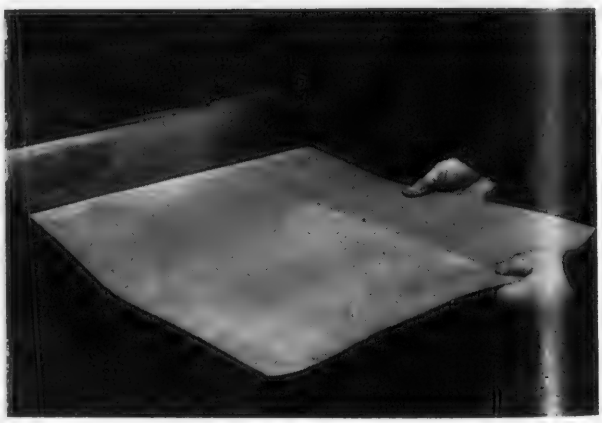


Fig. 2.—Here, a tolerance of ± .001 is easily being held on this piece of veneer face stock. Notice how well the "feeding" area of the machine is guarded.

Around the World in Forest Products Research and Development

1960 Forestry Congress Scheduled in U. S.

The Fifth World Forestry Congress will be held in the United States in 1960, it was announced last month following a meeting in Madrid, Spain, of the Council of the Food and Agriculture Organization of the United Nations. Proposed sites for the world-wide meeting are the states of Washington or Oregon.

The first such Congress to be held in the Western hemisphere, it will provide an opportunity for first-hand observation of the advance of technological development of the United States in recent years. The Pacific Northwest was selected because of its great forest wealth, complex and varied forest industries, national forests, research centers, forestry schools, and other forest institutions.

Past Congresses have been held in Rome in 1926, Budapest in 1936, Helsinki in 1949, and India in 1954. The meetings are composed of individuals rather than of government representatives and the responsibility for the technical and financial arrangements rests with the host country. The U.S.D.A. Forest Service has indicated its willingness to assume leadership in helping to develop plans and arrangements for the 1960 meeting.

Since FAO's formation, its Forestry Division has been made available to help the host country in planning the Congress, collecting background papers, and seconding officers. Attended by foresters, representatives of private organizations and forest industries, and experts in research and use of forest products, the Congresses have contributed to a general interchange of experience and knowledge which has served as a useful orientation to countries in the formulation of forest policies and has been a guide to FAO in its program of assistance to member countries.

Other Developments Around the World

Norway

• The 1956 annual report of the Norwegian Institute of Wood Working and Wood Technology, Oslo, describes the new research facilities completed at Blindern in October. The Institute now has its own chemical laboratory, library, photographic darkroom, and instrument laboratory. Apparatus and equipment is available for technical studies of sawing, machining, kiln-drying, preservation, and gluing operations.

Studies completed or now underway include: fundamental importance of the sawblade as regards sawing precision, comparisons of swaged-set and spring-set teeth, recovery studies in the sawmill, cutting before and after drying, advantages of various slab chippers, transportation of slabs and sawdust, three methods of drying sawdust, use of planer chips from a rotating cutter as raw material for chip boards, and gluing of preservative-treated Scotch pine.

Australia

• Results of more than 25 years of mechanical tests of properties of local and other timbers have been compiled in Bulletin 279, published by the Division of Forest Products, C. S. I. R. O., Melbourne, Australia. The bulletin is principally for the use of wood technologists, rather than persons engaged in the design of structures.

Detailed information is given on the properties of 85 Australian and 13 New Guinea timbers, as well as ramin and keruing from Borneo and Malaya. Properties covered include density, compression and shear strength, shock resistance, and hardness. Only those timbers have been included for which at least three trees have been sampled. In addition to the average properties, various statistics have been tabulated to show the variability of individual species and the precision with which the species average properties have been estimated.

Scanning World-Wide Forest Products Publications

Norway

Gravimetric and Absorptiometric Determination of Lignin in Pulp and Wood. V. Loras and F. Loschbrandt. Norsk Skogindustri V. 10, No. 11, Nov. 1956.

A study has been made of two gravimetric and two absorptiometric methods for the determination of lignin in pulp: a modified Halse method employing a mixture of hydrochloric and sulphuric acid; the CCA 5 method where 72 per cent sulphuric acid is used; the absorptiometric phosphoric acid method developed by Bethge, Gran, and Ohlsson; and the absorptiometric sulphuric acid method developed in the Norwegian Pulp and Paper Research Institute.

For the main part of the investigations, a series of spruce sulphite pulps, cooked at 125° and 135° C., was used. A series of sulphate pulps and two samples of spruce wood were also studied.

With sulphite pulp, the lignin values from the two gravimetric methods varied considerably. Both absorptiometric methods gave straight line relationships,

Both gravimetric methods gave the same results with sulphate pulps and wood. The absorptiometric methods obviously are not suitable for sulphate pulps because pulp slowly dissolved in the acids, with consequent spread in results.

Utilization of Sawdust in the Wallboard Industry. K. Helge. Norwegian Pulp and Paper Research Institute, Oslo. Norsk Skogindustri V. 11, No. 4, April 1957.

Studies were made of the mechanical refining of sawdust and shavings, and the possibilities of using sawdust as a raw material for fiber building boards. The experiments cover laboratory as well as plant investigations. Defiberizing experiments were performed in a P.F.I. laboratory mill and effects of the following factors evaluated: variations in chip size and additions of small quantities of sodium hydroxide or lime.

When small quantities of sodium hydroxide or lime were added immediately before the defiberizing operation, the paper forming properties were substantially improved. Addition of lime gave higher strength figures than addition of sodium hydroxide.

Three defiberizing methods were studied. The results showed that as much as 20 per cent of the ordinary raw materials could be replaced by sawdust defiberized by any of the methods. Trials with an Asplund defibrator with ordinary chips gave the best results over an extended period.

Abstracts From Current World Literature

Hardboard

Anon. New type of hardboard plant in Yugoslavia. *Paper Trade J.* 140, No. 50: 54–5 (Dec. 10, 1956).

A plant in Blazuj, near Sarajevo, Yugoslavia, is producing hardboard by a new process, utilizing the waste, principally peeling fall-off and cores, from a plywood plant based on beechwood. The plywood waste is chipped, treated in a weak caustic soda solution, cooked, and then conveyed to the Pallman "Turbo-Mills," steel refiners. The board is formed in forming presses, into which the stock flows automatically through a special measuring system. [Bul. Pap. Chem. V. 27, No. 6]

Particle Board

Maku, Takamaro, Sasaki, Hikaru, and Hamada, Ryozo. The effect of paraffin emulsion on the hygroscopic, swelling, and mechanical properties of chipboard. *J. Japan Wood Research Soc.* 2, no. 3: 130–2 (June, 1956). [In Japanese; English summary]

Three types of paraffin emulsions (emulsified with cationic, anionic, and nonionic surface-active agents) were applied as waterproofing agents to chipboard, and their effects on the hygroscopicity, swelling, and bending strength of the board were investigated. The chipboard was prepared by applying 7% by weight of urea resin to wood particles 2-3 cm. long, 4 mm. wide, and 0.15 mm. thick and hot pressing the mixture to 0.76–0.78 specific gravity. Even a low paraffin content (0.2-0.3% by weight) markedly reduced the swelling of chipboard on water immersion, but the hygroscopicity (moisture absorption) of the board was not noticeably affected even by 1% of paraffin. Bending strength and elastic modulus were likewise unaffected by the paraffin treatments. The method used for emulsifying the paraffin had no influence on the swelling behavior of chipboard in water. [Bul. Pap. Chem. V. 27, No. 6]

Properties

J. D. Brazier. Meranti, seraya and allied timbers. Forest Products Research Bulletin No. 36, 1956, 38 pp. 2*s* 6*d*

Since the war, the importance of Dipterocarps in the world market has been enhanced by the development of the timber resources of S. E. Asia. It may be several years before all the species are adequately described, but this volume helps to correlate trade, vernacular and botanical names, at the same time incorporating a description of the composition, economic importance and methods of distinguishing the timbers.

The range covered by these timbers is very wide, some being among the strongest and most durable in the tropics, while others are relatively soft, light in weight and perishable. The timbers described in this publication are produced by the four genera Anisoptera—13 species, Parashorea —7 species, Pentacme—3 species and Shorea—more than 100 species. Broadly speaking the meranti from Malaya, Sarawak and Indonesia, corresponds with the seraya from North Borneo and lavau from the Philippines.

Two defects are common in this class of timber; pinhole borers which attack the timber, either standing or felled but do not survive after seasoning, and brittleheart which, although it does not spread after felling, is a weakening defect. [F.D.C. Tech. Bul. V. 6, No. 32]

Plant Safety

Garrett, D. E., and Jordan, W. A. Put color to work in your plant. Chem. Eng. 63, no. 9:195–8 (Sept., 1956).

Recommendations for the functional use of color for coding equipment and painting work areas are given. Some advantages of color coding are minimization of errors, improved safety, greater operating efficiency, easier training, and better appearance. Psychological and other effects of color are discussed. [Bul. Pap. Chem. V. 27, No. 2]

Logging

Tuovinen, Arno and Wäre, Ilmari. Experience in tractor bundling. Paperi ja Puu 38, no. 11: 539–52, 554 (Nov., 1956). [In Finnish; English summary]

The widespread use of a wheeled-tractor transportation in Finland posed problems of bundling the loads transported by tractor sleigh. Four Finnish mills co-operated in short-term experiments to show several ways in which these problems can be solved. The following tentative recommendations are made for further work along the same lines. Ploughing is not recommended as a means of clearing snow from iced storage areas. Some method of compacting the snow should be developed. For hauling smaller quantities of timber, packed-snow roads can be used economically without further maintenance. The capacity and design of tractor-bundling equipment should be improved, aiming primarily at a universal sleigh type which can be converted for summer use, with improved mechanized unloading for short timber. The bunk and runner construction should be improved to make it better suited for the sidewise unloading of bundles. Short cordwood made into isolated bundles should be dropped behind the sleigh by anchoring rather than by tipping. Long cordwood and irregular bundles can be pulled from the side by the tractor itself, but driving to tipping ramps may prove better. Dropping to one side by anchoring and tipping with a hydraulic jack can also be used, whereas dropping by high speed turning is less recommended. In the bundling of sawn logs, dropping to the side by anchoring requires the use of bundle chains. Where these are unavailable, tipping ramps or pulling from the side should be used, especially for barked softwood logs. Unloading in bundles reduces working time and facilitates the operation. The boom crane provides mechanized loading for long timber, bolts, and logs. Similar devices should be developed for short timber, because manual loading is the weakest phase of tractor bundling. Bundle-delivery methods should be further improved, and special attention should be paid to driver training and good housekeeping practices in the storage yard. [Bul. Pap. Chem. V. 27, No. 5]

Bark Removal

Hooks, Ralph A. Barking of hardwoods and pine. Southern Pulp Paper Mfr. 19, no. 9: 46, 48 (Sept., 1956).

The author discusses some of the broad aspects of the problem of bark removal, covering variations in species and seasonal factors and methods of bark removal—sap peeling, barking drums, hydraulic barking, straight mechanical debarkers, and other methods. [Bul. Pap. Chem. V. 27, No. 4]

Chemical Utilization

Tanaka, Kiyoshi, and Tachi, Isamu. Studies on active charcoal. II. Preparation of active carbon by the steam process and in an air-circulating furnace. *Wood Research* (Japan) no. 12: 1-8 (Feb., 1954). [In Japanese; English summary]

The preparation of activated charcoal from branches and sawdust of various woods is described. In one method, the wood waste was burned differentially in an atmosphere of steam at 850°C. In this process, the duration of heating is critical. Judging from the discoloration of methylene blue, carbons prepared from *Quercus*, *Chamaecyparis*, and *Pinus* species were more active than those prepared from other woods. In the second method, 300–400 g. of sawdust were impregnated for 2–3 days with 750 ml. of a saturated borax-boric acid solution and then burned differentially with admission of air at 850°. Although the borax-boric acid impregnation increased the charcoal yield, it lowered the power to decolorize crude sugar solutions. Charcoal made from sawdust of *Cinnamomum*, *Eucalyptus*, and *Edgeworthia* species was more active than that from other woods in decolorizing crude sugar solution, whereas carbon made from *Chamaecyparis*, *Betula*, and *Edgeworthia* was superior in decolorizing methylene blue. [Bul. Pap. Chem. V. 27, No. 6]

The preparation of abstracts from world literature in many languages is so highly specialized and costly that the Forest Products Research Society has no abstracting service of its own. For the abstracts in this issue of the JOURNAL the Society is indebted to the respective abstract journals indicated, from which they have been selected with the kind permission of the editors. Readers wishing information in addition to that given in these abstracts should consult the original articles referred to. Copies or additional information can not be supplied by FPRS or the abstract journal. The journals from which abstracts are published in this issue are as follows:

BULLETIN OF THE INSTITUTE OF PAPER CHEMISTRY, published monthly at Appleton, Wisconsin by the Institute of Paper Chemistry, subscription price $25 per year. This Bulletin publishes over 3,600 abstracts per year on subjects of interest to manufacturers of pulp, paper, fiberboard and allied products.

CHEMICAL ABSTRACTS, published semimonthly by the American Chemical Society, Executive Office—1155 Sixteenth Street, NW, Washington 6, D. C., subscription price $60 per year plus postage. This abstract journal publishes many thousands of abstracts annually with broad coverage of world literature in the entire field of chemistry and allied subjects.

TECHNICAL BULLETIN OF THE FURNITURE DEVELOPMENT COUNCIL is published bimonthly by the Council at 11 Adelphi Terrace, London W. C. 2, England. The Technical Bulletin publishes hundreds of abstracts and reviews from world literature annually, relating to the various phases of the furniture manufacturing industry. Subscription price is $5 per year.

Review of Publications and FPRS Section Papers

Lumber and Pulpwood Potential in the Black Hills[1]

W. A. Kluender and C. R. Batten, Director and Forester, Agricultural and Resource Development Dept., Chicago and North Western Railway System, Chicago, Ill.

The forests of the Black Hills occupy about 1.5 million acres. Ponderosa pine is the primary tree species making up 95 per cent of the commercial volume. Approximately 75 per cent of the commercial forest land is owned by the U. S. Forest Service, 20 per cent by private owners, and 5 per cent by the states of South Dakota and Wyoming. Most of the commercial forest areas are of rolling topography which can be logged with commonly used mechanized equipment. Excellent pulpwood stands are located within 25 miles of railroad loading points and near all-weather roads.

The present lumber industry of the Black Hills consists primarily of a large number of small sawmills. About 30 of these have an annual production capacity of 200,000 board feet or over, only three of them producing over 5 million board feet each. The present annual saw timber harvest in the Black Hills is about 45 million board feet, while the allowable cut is about 70 million board feet. This difference between the actual and allowable annual cut leaves room for a sawmill industry expansion of at least 20 million board feet.

Small amounts of ponderosa pine pulpwood are now being produced and shipped to Lake States mills. Estimates as to a pulpwood harvest which could be sustained on an annual basis range from 100,000 to 120,000 cords. This represents a potential source of pulpwood which has not been tapped heretofore. Enough wood is available to support a moderate-size pulp mill and the possibilities of exporting pulpwood to midwest consuming centers are very favorable rate-wise when compared to other western pulpwood producing centers. It is estimated that the average acre of sawtimber contains a pulpwood volume of 7 cords. The average volume of cordwood on the pole stands has been estimated at 10 cords, although many stands support up to 20 cords per acre.

The equivalent of something over 8,000 cords of wood are cut each year for posts and small poles. The Black Hills lie in an advantageous position in relation to vast markets for these products in the northern Great Plains. There is opportunity for considerable expansion in the production of these products and such increase will not seriously interfere or compete with the production of pulpwood.

The two prospecti on which this summary is based provide additional information on quality of timber, logging and manufacturing costs, possibility of other products, tax questions, and other important information essential to evaluating the possibilities for timber-use and industry expansion in the Black Hills.

[1] Based on two prospecti prepared by the Chicago and North Western Railway System—"Lumber Manufacturing Possibilities in the Black Hills" and "The Pulpwood Resources of the Black Hills." Copies of these prospecti are available from W. A. Kluender, Director, Agricultural and Resource Development Dept., Chicago and North Western Railway System, 400 West Madison St., Chicago 6, Ill.

Glued Laminated Timber Beams in Building Construction

C. W. Saunders, Architect, Prentiss–Huddleston & Associates, Tallahassee, Fla. Florida–Georgia–Alabama Section Meeting, May 12–13, 1955.

Glued laminated timber supporting beams and solid timber decking are used as roof structure in modern school buildings in northern Florida. In public school work, it is necessary to find ways of economizing without sacrificing minimum space requirements, durability, maintenance, and general permanence of construction. The single-story building for smaller secondary and elementary schools proved to be most economical because of the elimination of heavy fireproof floor construction and fireproof access stairs.

Economy of deck material and number of beams led to the use of two-inch deck which is actually 1-5/8 inches thick, 16 feet long, and usually 5½ inches wide. The deck is tongue and grooved for continuous edge bond and is laid over beams eight feet apart, giving each board three points of support. Joints are staggered or alternated, making the deck strong enough for normal roof load. The under side of the structural deck can be used for the finished ceiling. If acoustical treatment is necessary or desirable, tile can be applied directly to the deck or to strips on the deck economically.

At Florida's location and latitude, it is necessary to apply a 1-inch thick rigid insulation board on top of the deck for winter heat conservation and for protection against the sun's heat in the early fall and spring. This also provides the necessary space to run wiring in conduit without leaving it exposed on the ceiling. The conduit is stapled down to the bare deck or over a single-ply of "drying-in" felt and the insulation worked around it before the finish roofing is applied. Wiring can also be run from switches to fixtures in neat metal mouldings exposed on the beam or deck.

There is a great difference in the volume of labor and material used with timber construction compared to steel. Because windows can be pushed up between the wood beams, better lighting is possible with lower walls and shorter columns. The beams and girts are erected usually by two carpenters, a small truck crane, and common labor. Carpenters nail down deck much as they nail down finish floor and the part below is then ready to paint. On top, a quick layer of protective felt is laid on as soon as the deck is started. The electricians then lay conduit, the insulation is applied, and the roofers complete the work.

There is a steadily growing use of this method of construction in many types of buildings. We have found this method economical in northern Florida in spite of the fact that many of the beams are fabricated in Oregon or Wisconsin and shipped whole to Florida. Construction time is shorter and costs lower. Churches find the design pleasing and the cost lower than in other types of construction.

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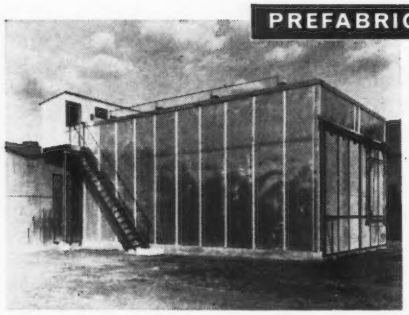

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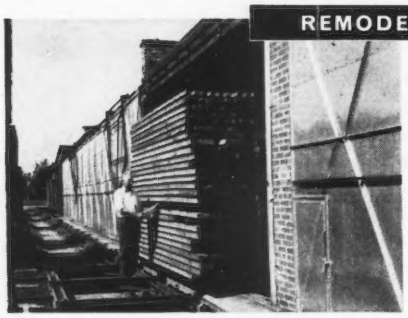

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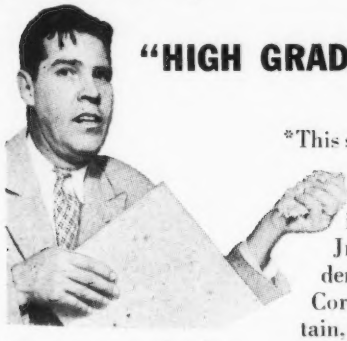

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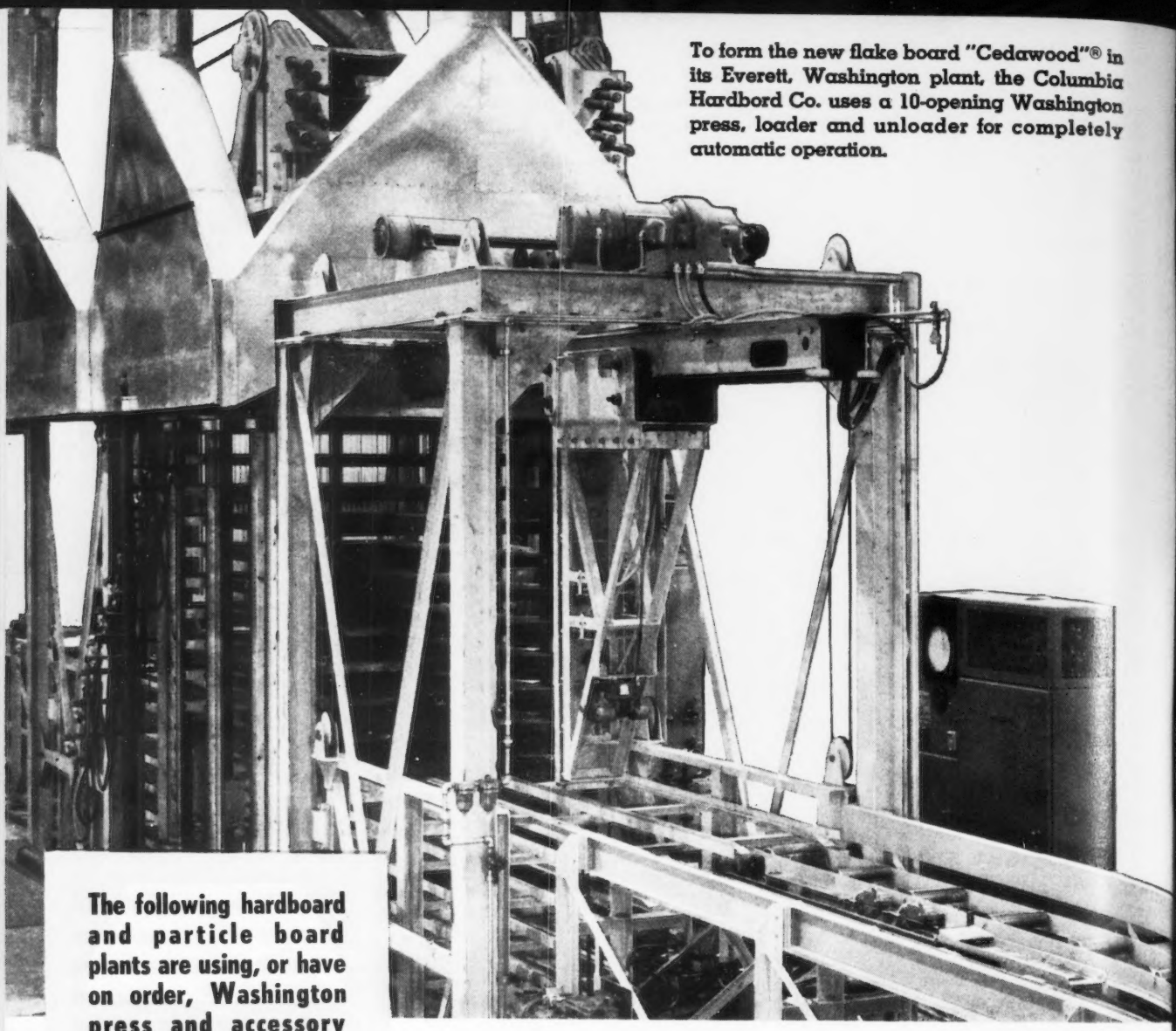

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